

US010194875B2

(12) **United States Patent**
DeFreitas et al.

(10) **Patent No.:** **US 10,194,875 B2**
(45) **Date of Patent:** **Feb. 5, 2019**

(54) **INTEGRATED MULTI-MODE MAMMOGRAPHY/TOMOSYNTHESIS X-RAY SYSTEM AND METHOD**

(58) **Field of Classification Search**
CPC .. A61B 6/00; A61B 6/02; A61B 6/025; A61B 6/04; A61B 6/44; A61B 6/4411;
(Continued)

(71) Applicant: **Hologic, Inc.**, Marlborough, MA (US)

(72) Inventors: **Kenneth DeFreitas**, Patterson, NY (US); **Thomas Farbizio**, Newtown, CT (US); **Baorui Ren**, Andover, MA (US); **Christopher Ruth**, Boxford, MA (US); **Ian Shaw**, Yorktown Heights, NY (US); **Andrew P. Smith**, Lexington, MA (US); **Jay Stein**, Boston, MA (US)

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,365,575 A * 1/1968 Strax A61B 6/502
378/171
3,502,878 A 3/1970 Stewart
(Continued)

(73) Assignee: **Hologic, Inc.**, Marlborough, MA (US)

FOREIGN PATENT DOCUMENTS

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

DE 102004051401 5/2006
EP 0775467 5/1997
(Continued)

(21) Appl. No.: **15/411,502**

OTHER PUBLICATIONS

(22) Filed: **Jan. 20, 2017**

“Essentials for life: Senographe Essential Full-Field Digital Mammography system”, GE Health-care Brochure, MM-0132-05.06-EN-US, 2006, 12 pgs.
(Continued)

(65) **Prior Publication Data**

US 2017/0128028 A1 May 11, 2017

Related U.S. Application Data

(63) Continuation of application No. 14/498,476, filed on Sep. 26, 2014, now Pat. No. 9,549,709, which is a
(Continued)

Primary Examiner — Anastasia Midkiff

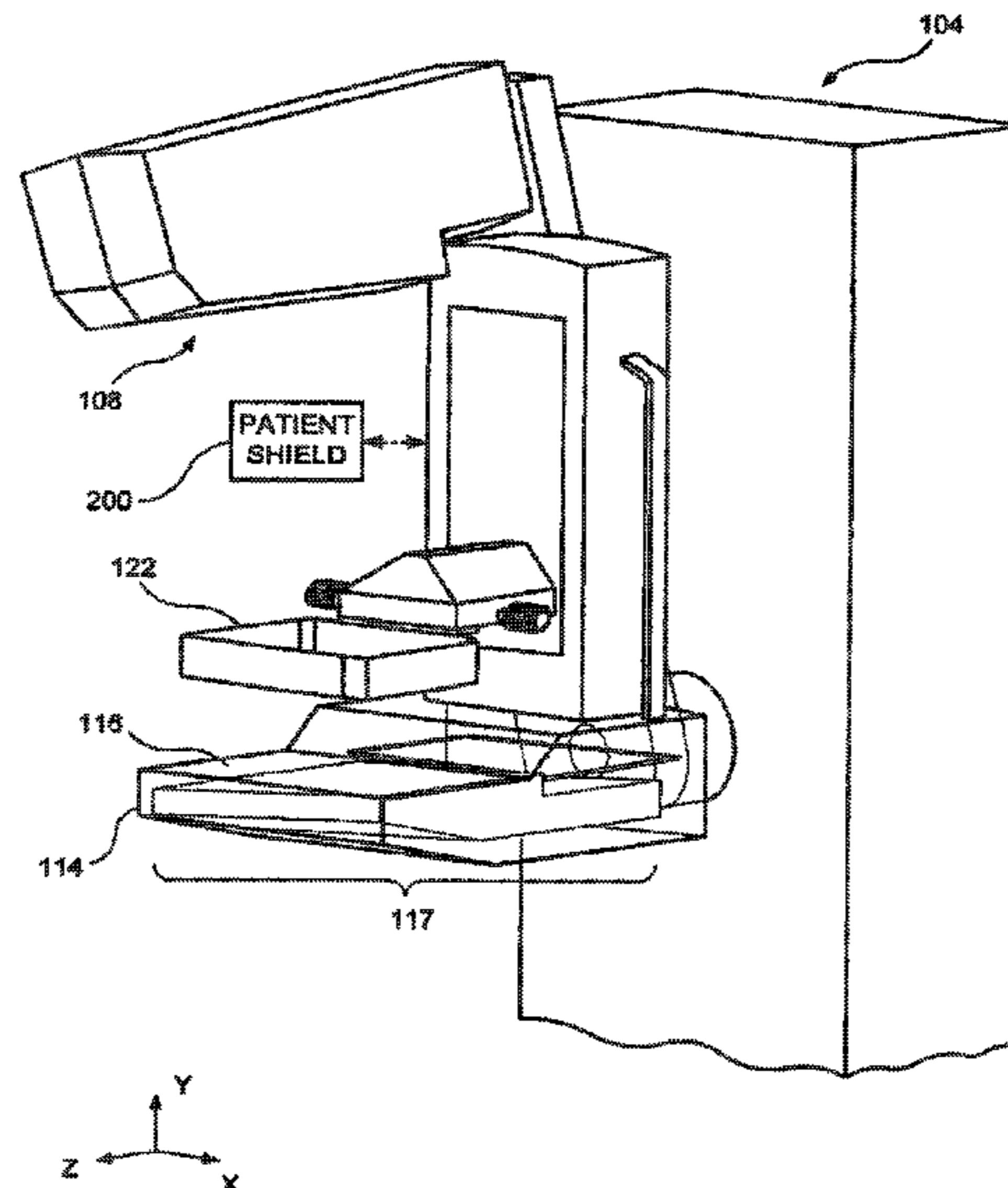
(51) **Int. Cl.**
A61B 6/04 (2006.01)
A61B 6/02 (2006.01)
(Continued)

(57) **ABSTRACT**

A system for multi-mode breast x-ray imaging which comprises a compression arm assembly for compressing and immobilizing a breast for x-ray imaging, an x-ray tube assembly, an x-ray image receptor, and a patient shield is provided. The system is configured for a plurality of imaging protocols and modes.

(52) **U.S. Cl.**
CPC **A61B 6/107** (2013.01); **A61B 6/025** (2013.01); **A61B 6/4417** (2013.01);
(Continued)

18 Claims, 16 Drawing Sheets



Related U.S. Application Data

continuation of application No. 14/058,385, filed on Oct. 21, 2013, now Pat. No. 9,066,706, which is a continuation of application No. 13/462,342, filed on May 2, 2012, now Pat. No. 8,565,374, which is a continuation of application No. 12/954,971, filed on Nov. 29, 2010, now Pat. No. 8,175,219, which is a continuation of application No. 11/791,601, filed as application No. PCT/US2005/042613 on Nov. 23, 2005, now Pat. No. 7,869,563.

(60) Provisional application No. 60/631,296, filed on Nov. 26, 2004.

(51) **Int. Cl.**

A61B 6/10 (2006.01)

A61B 6/00 (2006.01)

(52) **U.S. Cl.**

CPC *A61B 6/4452* (2013.01); *A61B 6/502* (2013.01); *A61B 6/4291* (2013.01); *A61B 6/482* (2013.01); *G06T 2207/30068* (2013.01)

(58) **Field of Classification Search**

CPC ... A61B 6/4417; A61B 6/4429; A61B 6/4435; A61B 6/0414; A61B 6/4291; A61B 6/4441; A61B 6/445248; A61B 6/50; A61B 6/502; A61B 6/54; A61B 6/545; A61B 6/58; A61B 6/587-6/589; G06T 2207/30; G06T 2207/30068

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,863,073 A	1/1975	Wagner
3,971,950 A	7/1976	Evans et al.
4,160,906 A	7/1979	Daniels et al.
4,310,766 A	1/1982	Finkenzeller et al.
4,380,086 A	4/1983	Vagi
4,496,557 A	1/1985	Malen et al.
4,513,433 A	4/1985	Weiss et al.
4,542,521 A	9/1985	Hahn et al.
4,559,641 A	12/1985	Caugant et al.
4,662,379 A	5/1987	Macovski
4,706,269 A	11/1987	Reina et al.
4,721,856 A *	1/1988	Saotome G03B 42/02 250/583
4,744,099 A	5/1988	Huettenrauch et al.
4,752,948 A	6/1988	MacMahon
4,760,589 A	7/1988	Siczek et al.
4,773,086 A	9/1988	Fujita et al.
4,773,087 A	9/1988	Plewes
4,819,258 A	4/1989	Kleinman et al.
4,821,727 A	4/1989	Levene et al.
4,969,174 A	11/1990	Scheid et al.
4,989,227 A	1/1991	Tirelli et al.
5,018,176 A	5/1991	Romeas et al.
RE33,634 E	7/1991	Yanaki
5,029,193 A	7/1991	Saffer
5,051,904 A	9/1991	Griffith
5,078,142 A	1/1992	Siczek et al.
5,163,075 A	11/1992	Lubinsky et al.
5,164,976 A	11/1992	Scheid et al.
5,199,056 A	3/1993	Darrah
5,212,637 A	5/1993	Saxena
5,240,011 A	8/1993	Assa
5,256,370 A	10/1993	Slattery et al.
5,289,520 A	2/1994	Pellegrino et al.
5,291,539 A	3/1994	Thumann et al.
5,359,637 A	10/1994	Webber
5,365,562 A	11/1994	Toker
5,415,169 A	5/1995	Siczek et al.

5,426,685 A	6/1995	Pellegrino et al.
5,452,367 A	9/1995	Bick et al.
5,506,877 A	4/1996	Niklason et al.
5,526,394 A	6/1996	Siczek et al.
5,539,797 A	7/1996	Heidsieck et al.
5,553,111 A	9/1996	Moore et al.
5,592,562 A	1/1997	Rooks
5,594,769 A	1/1997	Pellegrino et al.
5,596,200 A	1/1997	Sharma et al.
5,598,454 A	1/1997	Franetzke et al.
5,609,152 A	3/1997	Pellegrino et al.
5,627,869 A	5/1997	Andrew et al.
5,657,362 A	8/1997	Giger et al.
5,668,844 A	9/1997	Webber
5,668,889 A	9/1997	Hara
5,706,327 A	1/1998	Adamkowski et al.
5,719,952 A	2/1998	Rooks
5,735,264 A	4/1998	Siczek et al.
5,769,086 A	6/1998	Ritchart et al.
5,803,912 A	9/1998	Siczek et al.
5,818,898 A	10/1998	Tsukamoto et al.
5,828,722 A	10/1998	Ploetz et al.
5,844,965 A	12/1998	Galkin
5,872,828 A	2/1999	Niklason et al.
5,878,104 A	3/1999	Ploetz
5,896,437 A	4/1999	Ploetz
5,941,832 A	8/1999	Tumey et al.
5,970,118 A	10/1999	Sokolov
5,986,662 A	11/1999	Argiro et al.
5,999,836 A	12/1999	Nelson et al.
6,005,907 A	12/1999	Ploetz
6,022,325 A	2/2000	Siczek et al.
6,075,879 A	6/2000	Roehrig et al.
6,091,841 A	7/2000	Rogers et al.
6,137,527 A	10/2000	Abdel-Malek et al.
6,141,398 A	10/2000	He et al.
6,149,301 A	11/2000	Kautzer et al.
6,175,117 B1	1/2001	Komardin et al.
6,196,715 B1	3/2001	Nambu et al.
6,207,958 B1	3/2001	Giakos
6,216,540 B1	4/2001	Nelson et al.
6,219,059 B1	4/2001	Argiro
6,233,473 B1	5/2001	Shepherd et al.
6,243,441 B1	6/2001	Zur
6,244,507 B1	6/2001	Garland
6,256,370 B1	7/2001	Yavuz
6,272,207 B1	8/2001	Tang
6,289,235 B1	9/2001	Webber et al.
6,292,530 B1	9/2001	Yavus et al.
6,327,336 B1	12/2001	Gingold et al.
6,341,156 B1	1/2002	Baetz et al.
6,345,194 B1	2/2002	Nelson et al.
6,375,352 B1	4/2002	Hewes et al.
6,411,836 B1	6/2002	Patel et al.
6,415,015 B2	7/2002	Nicolas et al.
6,442,288 B1	8/2002	Haerer et al.
6,459,925 B1	10/2002	Nields et al.
6,480,565 B1	11/2002	Ning
6,490,476 B1	12/2002	Townsend et al.
6,501,819 B2	12/2002	Unger et al.
6,556,655 B1	4/2003	Chichereau et al.
6,574,304 B1	6/2003	Hsieh et al.
6,574,629 B1	6/2003	Cooke, Jr. et al.
6,597,762 B1	7/2003	Ferrant et al.
6,611,575 B1	8/2003	Alyassin et al.
6,620,111 B2	9/2003	Stephens et al.
6,626,849 B2	9/2003	Huitema et al.
6,633,674 B1	10/2003	Barnes et al.
6,638,235 B2	10/2003	Miller et al.
6,647,092 B2	11/2003	Eberhard et al.
6,744,848 B2	6/2004	Stanton et al.
6,748,044 B2	6/2004	Sabol et al.
6,751,285 B2	6/2004	Eberhard et al.
6,758,824 B1	7/2004	Miller et al.
6,813,334 B2	11/2004	Koppe et al.
6,882,700 B2	4/2005	Wang et al.
6,885,724 B2	4/2005	Li et al.
6,909,790 B2	6/2005	Tumey et al.
6,909,792 B1	6/2005	Carrott et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

6,912,319 B1	6/2005	Barnes et al.	2003/0194051 A1	10/2003	Wang et al.
6,940,943 B2	9/2005	Claus et al.	2003/0194121 A1	10/2003	Eberhard et al.
6,957,099 B1	10/2005	Arnone et al.	2003/0210254 A1	11/2003	Doan et al.
6,970,531 B2	11/2005	Eberhard et al.	2003/0212327 A1	11/2003	Wang et al.
6,978,040 B2	12/2005	Berestov	2003/0215120 A1	11/2003	Uppaluri et al.
6,987,831 B2	1/2006	Ning	2004/0008809 A1	1/2004	Webber
6,999,554 B2	2/2006	Mertelmeier	2004/0066882 A1	4/2004	Eberhard et al.
7,110,490 B2	9/2006	Eberhard et al.	2004/0066884 A1	4/2004	Hermann Claus et al.
7,110,502 B2	9/2006	Tsuji	2004/0066904 A1	4/2004	Eberhard et al.
7,123,684 B2	10/2006	Jing et al.	2004/0070582 A1	4/2004	Smith et al.
7,127,091 B2	10/2006	Op De Beek et al.	2004/0094167 A1	5/2004	Brady et al.
7,142,633 B2	11/2006	Eberhard et al.	2004/0101095 A1	5/2004	Jing et al.
7,245,694 B2	7/2007	Jing et al.	2004/0109529 A1	6/2004	Eberhard et al.
7,302,031 B2	11/2007	Hjarn et al.	2004/0146221 A1	7/2004	Siegel et al.
7,315,607 B2	1/2008	Ramsauer	2004/0171986 A1	9/2004	Tremaglio, Jr. et al.
7,319,735 B2	1/2008	Defreitas et al.	2004/0267157 A1	12/2004	Miller et al.
7,323,692 B2	1/2008	Rowlands et al.	2005/0049521 A1	3/2005	Miller et al.
7,430,272 B2	9/2008	Jing et al.	2005/0063509 A1	3/2005	DeFreitas et al.
7,443,949 B2	10/2008	Defreitas et al.	2005/0078797 A1	4/2005	Danielsson et al.
7,577,282 B2	8/2009	Gkanatsios et al.	2005/0105679 A1	5/2005	Wu et al.
7,583,786 B2	9/2009	Jing et al.	2005/0113681 A1	5/2005	DeFreitas et al.
7,609,806 B2	10/2009	Defreitas et al.	2005/0113715 A1	5/2005	Schwindt et al.
7,616,801 B2	11/2009	Gkanatsios et al.	2005/0129172 A1	6/2005	Mertelmeier
7,630,531 B2	12/2009	Chui	2005/0135555 A1	6/2005	Claus et al.
7,630,533 B2	12/2009	Ruth et al.	2005/0135664 A1	6/2005	Kaufhold et al.
7,688,940 B2	3/2010	Defreitas et al.	2005/0226375 A1	10/2005	Eberhard et al.
7,697,660 B2	4/2010	Ning	2006/0030784 A1	2/2006	Miller et al.
7,702,142 B2	4/2010	Ren et al.	2006/0074288 A1	4/2006	Kelly
7,760,853 B2	7/2010	Jing et al.	2006/0098855 A1	5/2006	Gkanatsios et al.
7,760,924 B2	7/2010	Ruth et al.	2006/0129062 A1	6/2006	Nicoson et al.
7,792,245 B2	9/2010	Hitzke et al.	2006/0155209 A1	7/2006	Miller et al.
7,831,296 B2	11/2010	Defreitas et al.	2006/0269041 A1	11/2006	Mertelmeier
7,869,563 B2	1/2011	Defreitas et al.	2006/0291618 A1	12/2006	Eberhard et al.
7,881,428 B2	2/2011	Jing et al.	2007/0030949 A1	2/2007	Jing et al.
7,894,646 B2	2/2011	Shirahata et al.	2007/0036265 A1	2/2007	Jing et al.
7,916,915 B2	3/2011	Gkanatsios et al.	2007/0076844 A1	4/2007	Defreitas et al.
7,949,091 B2	5/2011	Jing et al.	2007/0078335 A1	4/2007	Horn
7,986,765 B2	7/2011	Defreitas et al.	2007/0140419 A1	6/2007	Souchay
7,991,106 B2	8/2011	Ren et al.	2007/0223651 A1	9/2007	Wagenaar et al.
8,131,049 B2	3/2012	Ruth et al.	2007/0225600 A1	9/2007	Weibrecht et al.
8,155,421 B2	4/2012	Ren et al.	2007/0242800 A1	10/2007	Jing et al.
8,170,320 B2	5/2012	Smith et al.	2008/0019581 A1	1/2008	Gkanatsios et al.
8,175,219 B2	5/2012	Defreitas et al.	2008/0045833 A1	2/2008	Defreitas et al.
8,285,020 B2	10/2012	Gkanatsios et al.	2008/0101537 A1	5/2008	Sendai
8,416,915 B2	4/2013	Jing et al.	2008/0112534 A1	5/2008	Defreitas
8,452,379 B2	5/2013	DeFreitas et al.	2008/0130979 A1	6/2008	Ren
8,559,595 B2	10/2013	Defreitas et al.	2008/0212861 A1	9/2008	Durgan et al.
8,565,372 B2	10/2013	Stein et al.	2009/0003519 A1	1/2009	Defreitas et al.
8,565,374 B2	10/2013	DeFreitas et al.	2009/0010384 A1	1/2009	Jing et al.
8,571,289 B2	10/2013	Ruth et al.	2009/0080594 A1	3/2009	Brooks et al.
8,712,127 B2	4/2014	Ren et al.	2009/0080602 A1	3/2009	Brooks et al.
8,831,171 B2	9/2014	Jing et al.	2009/0135997 A1	5/2009	Defreitas et al.
9,042,612 B2	5/2015	Gkanatsios et al.	2009/0141859 A1	6/2009	Gkanatsios et al.
9,066,706 B2	6/2015	Defreitas et al.	2009/0213987 A1	8/2009	Stein et al.
9,460,508 B2	10/2016	Gkanatsios et al.	2009/0238424 A1	9/2009	Arakita et al.
9,498,175 B2	11/2016	Stein et al.	2009/0268865 A1	10/2009	Ren et al.
9,549,709 B2	1/2017	DeFreitas et al.	2009/0296882 A1	12/2009	Gkanatsios
2001/0038681 A1	11/2001	Stanton et al.	2009/0304147 A1	12/2009	Jing et al.
2002/0012450 A1	1/2002	Tsujii	2010/0034450 A1	2/2010	Mertelmeier
2002/0048343 A1	4/2002	Launay et al.	2010/0054400 A1	3/2010	Ren
2002/0050986 A1	5/2002	Inouc et al.	2010/0086188 A1	4/2010	Ruth
2002/0070970 A1	6/2002	Wood et al.	2010/0150306 A1	6/2010	Defreitas et al.
2002/0075997 A1	6/2002	Unger et al.	2010/0195882 A1	8/2010	Ren
2002/0090055 A1	7/2002	Zur et al.	2010/0226475 A1	9/2010	Smith
2002/0122533 A1	9/2002	Marie et al.	2010/0290585 A1	11/2010	Eliasson
2003/0007598 A1	1/2003	Wang et al.	2011/0069809 A1	3/2011	Defreitas et al.
2003/0018272 A1	1/2003	Treado et al.	2011/0178389 A1	7/2011	Kumar et al.
2003/0026386 A1	2/2003	Tang et al.	2011/0234630 A1	9/2011	Batman et al.
2003/0072409 A1	4/2003	Kaufhold et al.	2012/0051502 A1*	3/2012	Ohta A61B 6/00 378/37
2003/0072417 A1	4/2003	Kaufhold et al.	2013/0028374 A1	1/2013	Gkanatsios et al.
2003/0073895 A1	4/2003	Nields et al.	2013/0272494 A1	10/2013	DeFreitas et al.
2003/0095624 A1	5/2003	Eberhard et al.	2014/0044230 A1	2/2014	Stein et al.
2003/0097055 A1	5/2003	Yanof et al.	2014/0044231 A1	2/2014	Defreitas et al.
2003/0169847 A1	9/2003	Karellas et al.	2014/0086471 A1	3/2014	Ruth et al.
2003/0194050 A1	10/2003	Eberhard	2014/0098935 A1	4/2014	Defreitas et al.
			2014/0232752 A1	8/2014	Ren et al.
			2014/0376690 A1	12/2014	Jing et al.
			2015/0049859 A1	2/2015	DeFreitas et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

2015/0160848 A1 6/2015 Gkanatsios et al.
 2015/0310611 A1 10/2015 Gkanatsios et al.
 2016/0270742 A9 9/2016 Stein et al.
 2017/0024113 A1 1/2017 Gkanatsios et al.
 2017/0135650 A1 5/2017 Stein et al.

FOREIGN PATENT DOCUMENTS

EP	0982001	3/2000
EP	1428473	6/2004
EP	1759637	3/2007
EP	1569556	4/2012
EP	2602743	11/2014
JP	53151381	4/1972
JP	53151381 U	11/1978
JP	2001-346786	12/2001
JP	2002219124	8/2002
JP	2006-231054	9/2006
JP	2007-50264	3/2007
JP	2007-521911	8/2007
JP	2007229269	9/2007
JP	2008-67933	3/2008
JP	200886471	4/2008
JP	2009500048	1/2009
WO	WO 90/05485	5/1990
WO	WO 98/16903	4/1998
WO	WO 00/51484	9/2000
WO	WO 03/020114	3/2003
WO	WO 2003/057564	7/2003
WO	WO 2004/043535	5/2004
WO	WO 2005/051197	6/2005
WO	WO 2005/110230	11/2005
WO	WO 2005/112767	12/2005
WO	WO 2006/055830	5/2006
WO	WO 2006/058160	6/2006

OTHER PUBLICATIONS

“Filtered Back Projection,” (NYGREN) published May 8, 2007;
 URL:<http://web.archive.org/web/19991010131715/http://www.owl.net.rice.edu/~.about.elec539/Projects97/cult/node2.html>, 2 pgs.

“Lorad Selenia” Document B-BI-SEO US/Intl (May 2006) copyright Hologic 2006, 12 pgs.

ACRIN website, located at <https://www.acrin.org/PATIENTS/ABOUTIMAGINGEXAMSANDAGENTS/ABOUTMAMMOGRAPHYANDTOMOSYNTHESIS.aspx>, “About Mammography and Tomosynthesis”, obtained online on Dec. 8, 2015, 5 pgs.

American College of Radiology website, located at <http://www.acr.org/FAQs/DBT-FAQ>, “Digital Breast Tomosynthesis FAQ for Insurers”, obtained online on Dec. 8, 2015, 2 pages.

Aslund, Magnus, “Digital Mammography with a Photon Counting Detector in a Scanned Multislit Geometry”, Doctoral Thesis, Dept of Physics, Royal Institute of Technology, Stockholm, Sweden, Apr. 2007, 51 pages.

Chan, Heang-Ping et al., “ROC study of the effect of stereoscopic imaging on assessment of breast lesions”, *Medical Physics*, vol. 32, No. 4, Apr. 2005, 7 pgs.

Cole, Elodia, et al., “The Effects of Gray Scale Image Processing on Digital Mammography Interpretation Performance”, *Academic Radiology*, vol. 12, No. 5, pp. 585-595, May 2005.

Digital Clinical Reports, Tomosynthesis, GE Brochure 98-5493, Nov. 1998, 8 pgs.

Dobbins, James T., “Digital x-ray tomosynthesis: current state of the art and clinical potential,” *Physics in Medicine and Biology*, Taylor and Francis Ltd, London GB, vol. 48, No. 19, Oct. 7, 2003, 42 pages.

Federica Pediconi et al., “Color-coded automated signal intensity-curve for detection and characterization of breast lesions: Preliminary evaluation of a new software for MR-based breast imaging”, *International Congress Series 1281 (2005) 1081-1086*.

Grant, David G., “Tomosynthesis: a three-dimensional imaging technique”, *IEEE Trans. Biomed. Engineering*, vol. BME-19, #1, Jan. 1972, pp. 20-28.

Kita et al., “Correspondence between different view breast X-rays using simulation of breast deformation”, *Proceedings 1998 IEE Computer Society Conference on Computer Vision and Pattern Recognition*, Santa Barbara, CA, Jun. 23-25, 1998, pp. 700-707.

Mammographic Accreditation Phantom, <http://www.cirsinc.com/pdfs/015cp.pdf>. (2006), 2 pgs.

Niklason, Loren T. et al., “Digital Tomosynthesis in Breast Imaging”, *Radiology*, Nov. 1997, vol. 205, No. 2, pp. 399-406.

Pisano, Etta D., “Digital Mammography”, *Radiology*, vol. 234, No. 2, Feb. 2005, pp. 353-362.

Senographe 700 & 800T (GE); 2-page download on Jun. 22, 2006 from www.gehealthcare.com/inen/rad/whe/products/mswh800t.html; Figures 1-7 on 4 sheets re lateral shift compression paddle, 2 pgs.

Smith, A., “Fundamentals of Breast Tomosynthesis”, White Paper, Hologic Inc., WP-00007, Jun. 2008, 8 pgs.

Smith, Andrew, PhD, “Full Field Breast Tomosynthesis”, Hologic White Paper, Oct. 2004, 6 pgs.

Wheeler F. W., et al. “Micro-Calcification Detection in Digital Tomosynthesis Mammography”, *Proceedings of SPIE, Conf-Physics of Semiconductor Devices*, Dec. 11, 2001 to Dec. 15, 2001, Delhi, SPIE, US, vol. 6144, Feb. 13, 2006, 12 pgs.

Wu, Tao, et al. “Tomographic Mammography Using a Limited Number of Low-Dose Cone-Beam Projection Images” *Medical Physics*, AIP, Melville, NY, vol. 30, No. 3, Mar. 1, 2003, p. 365-380.

Japanese Office Action mailed in Application 2016-087710, dated Mar. 1, 2017, 5 pages.

Japanese Office Action mailed in Application 2017-001579, dated Mar. 29, 2017, 1 page. (No English Translation.).

* cited by examiner

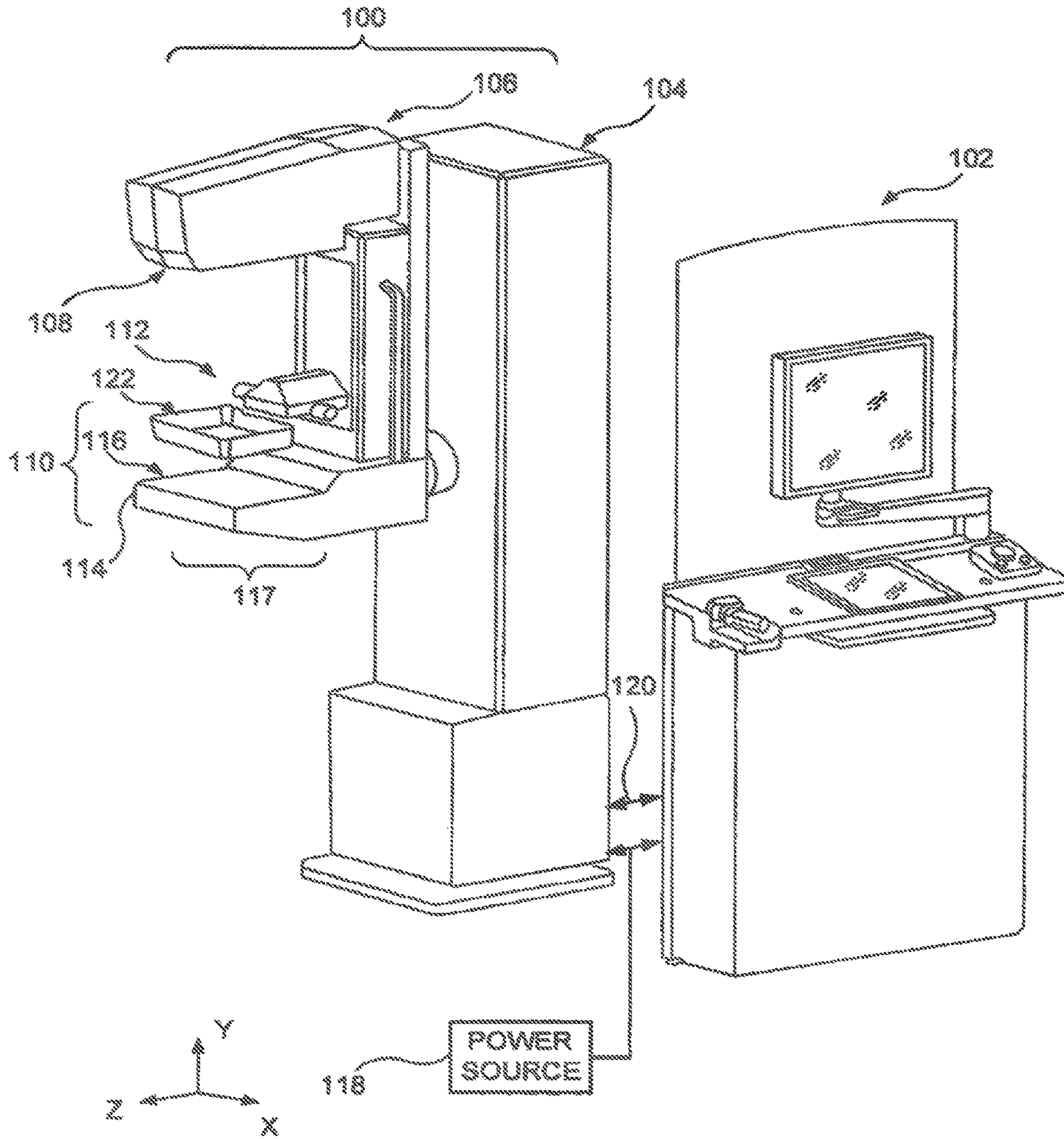


FIG. 1

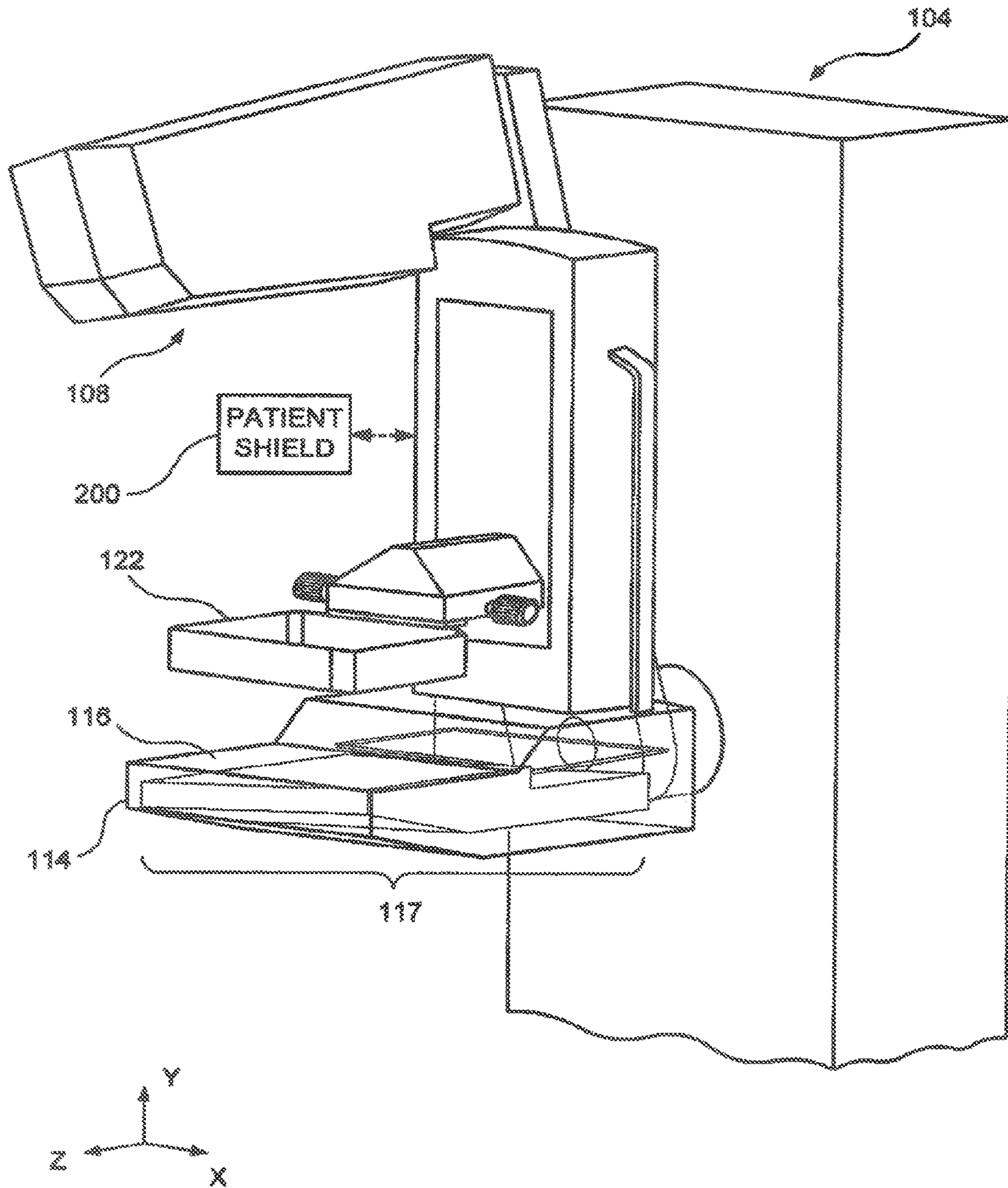


FIG. 2

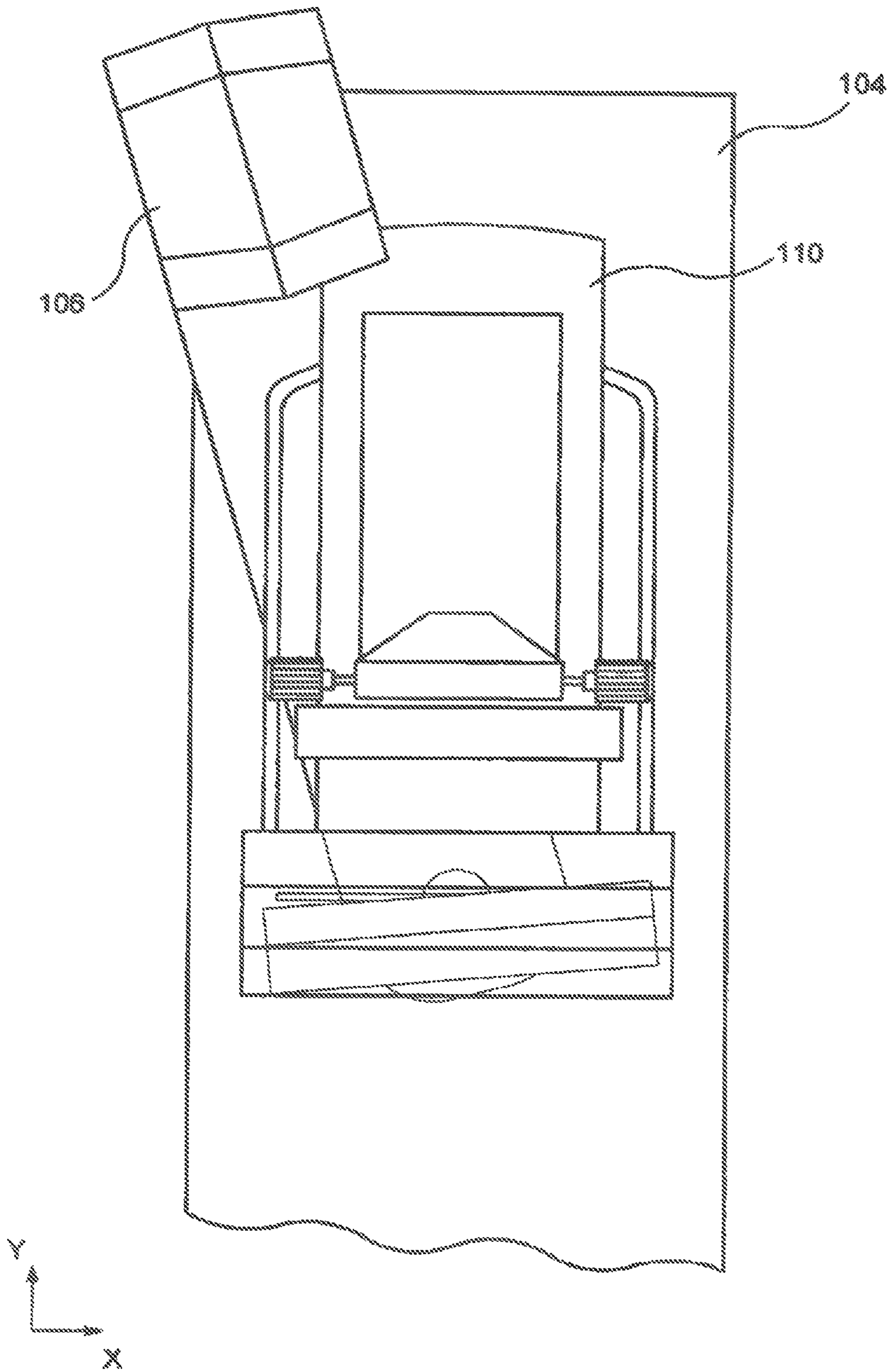
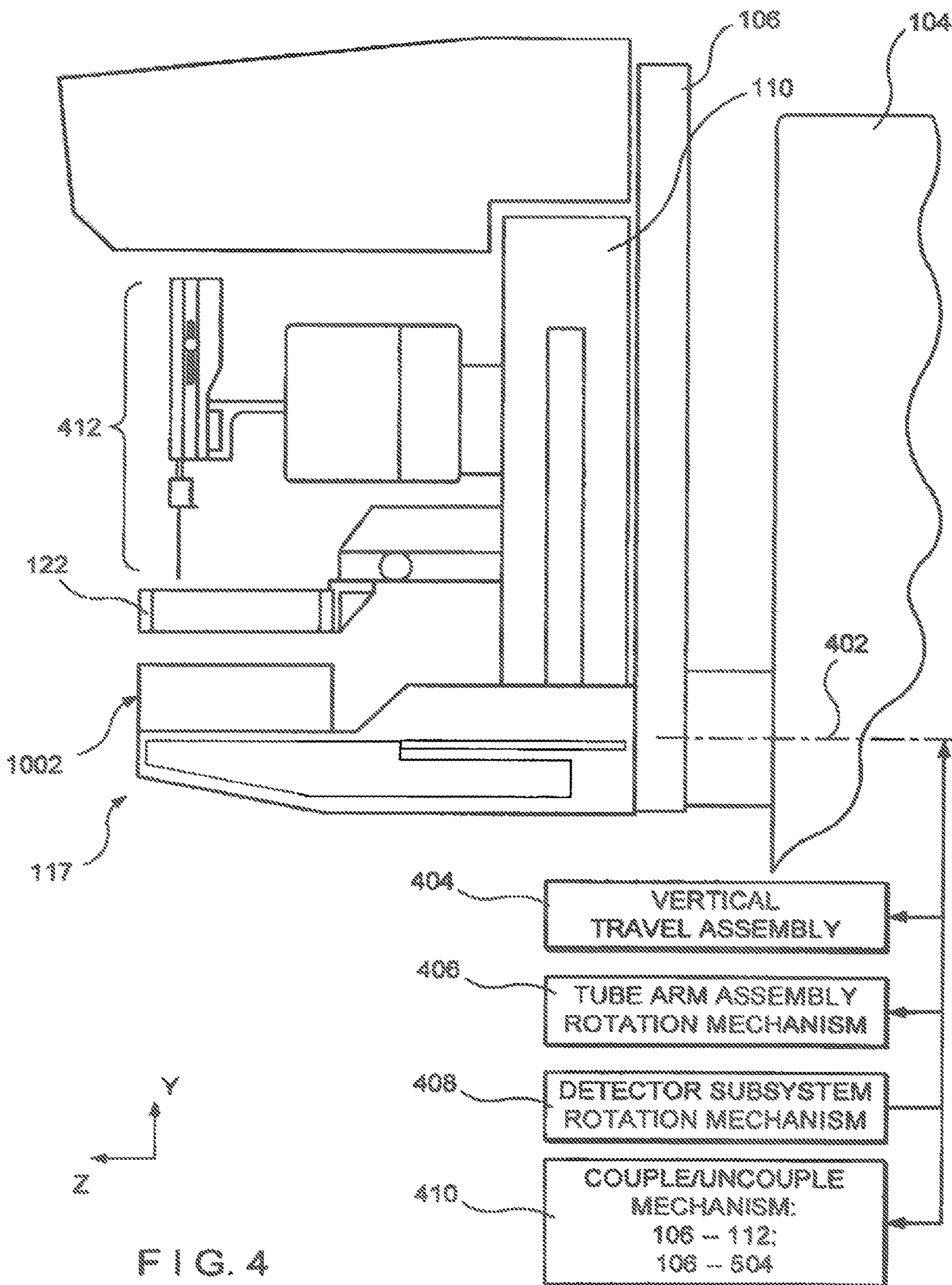


FIG. 3



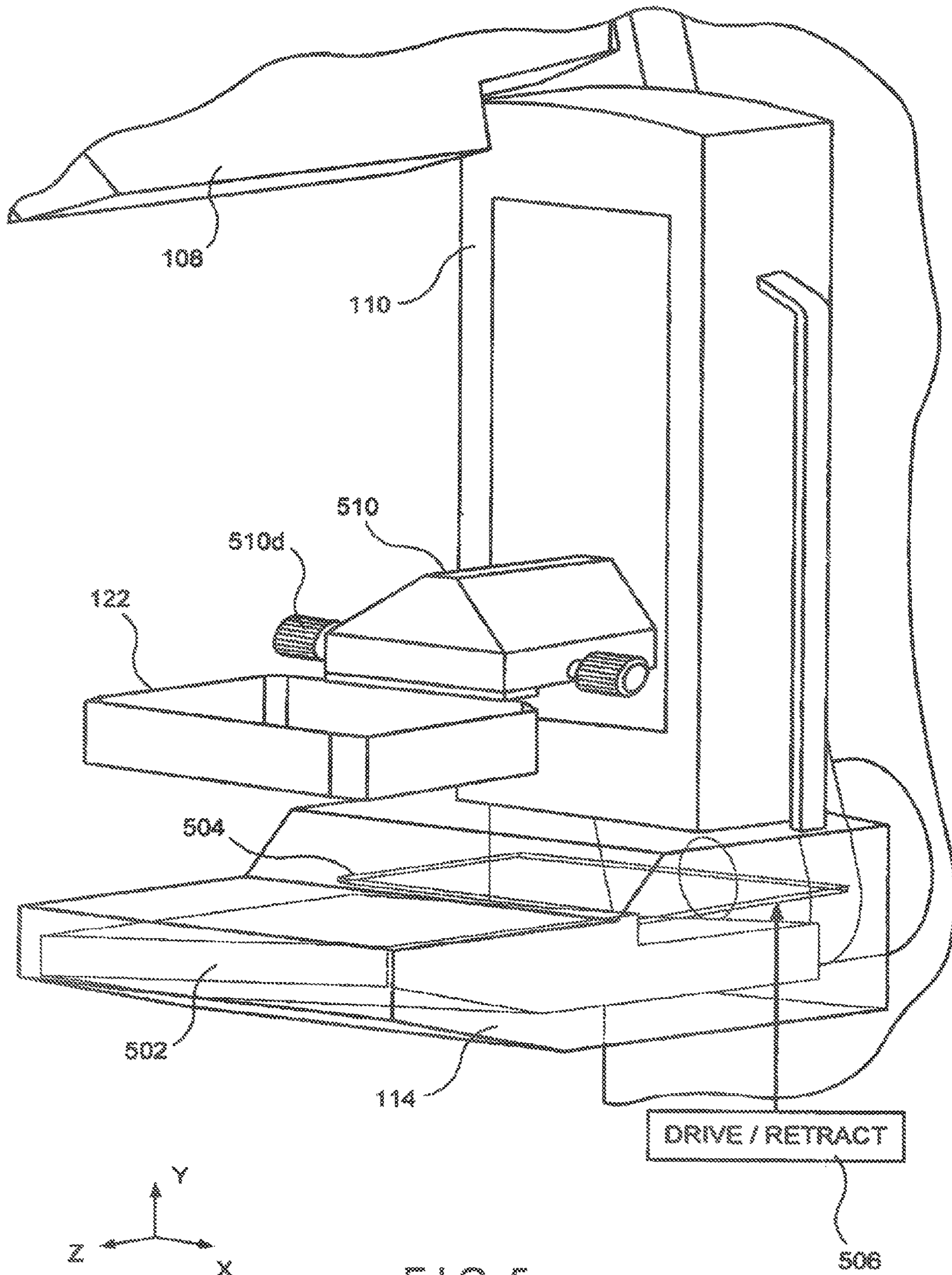


FIG. 5

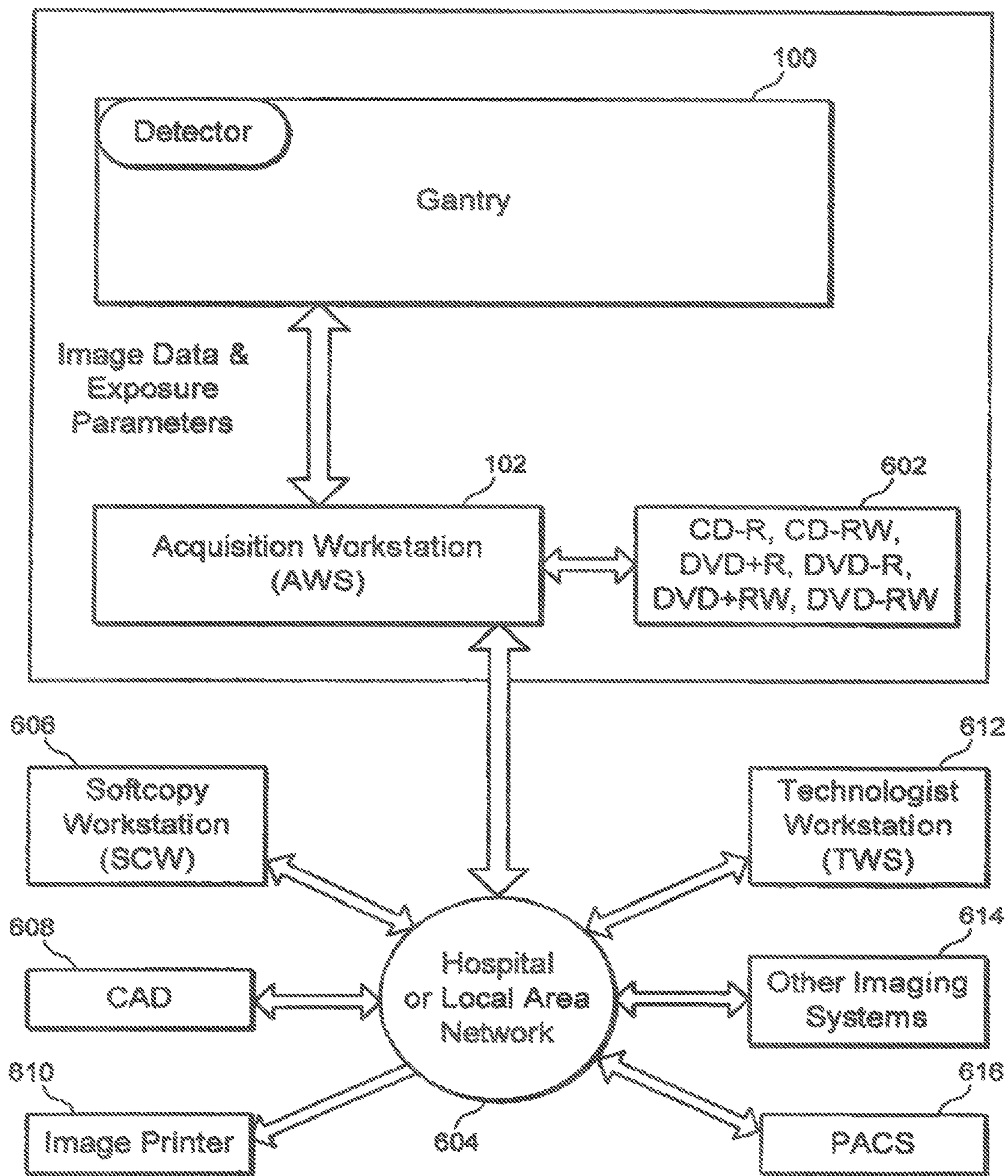


FIG. 6

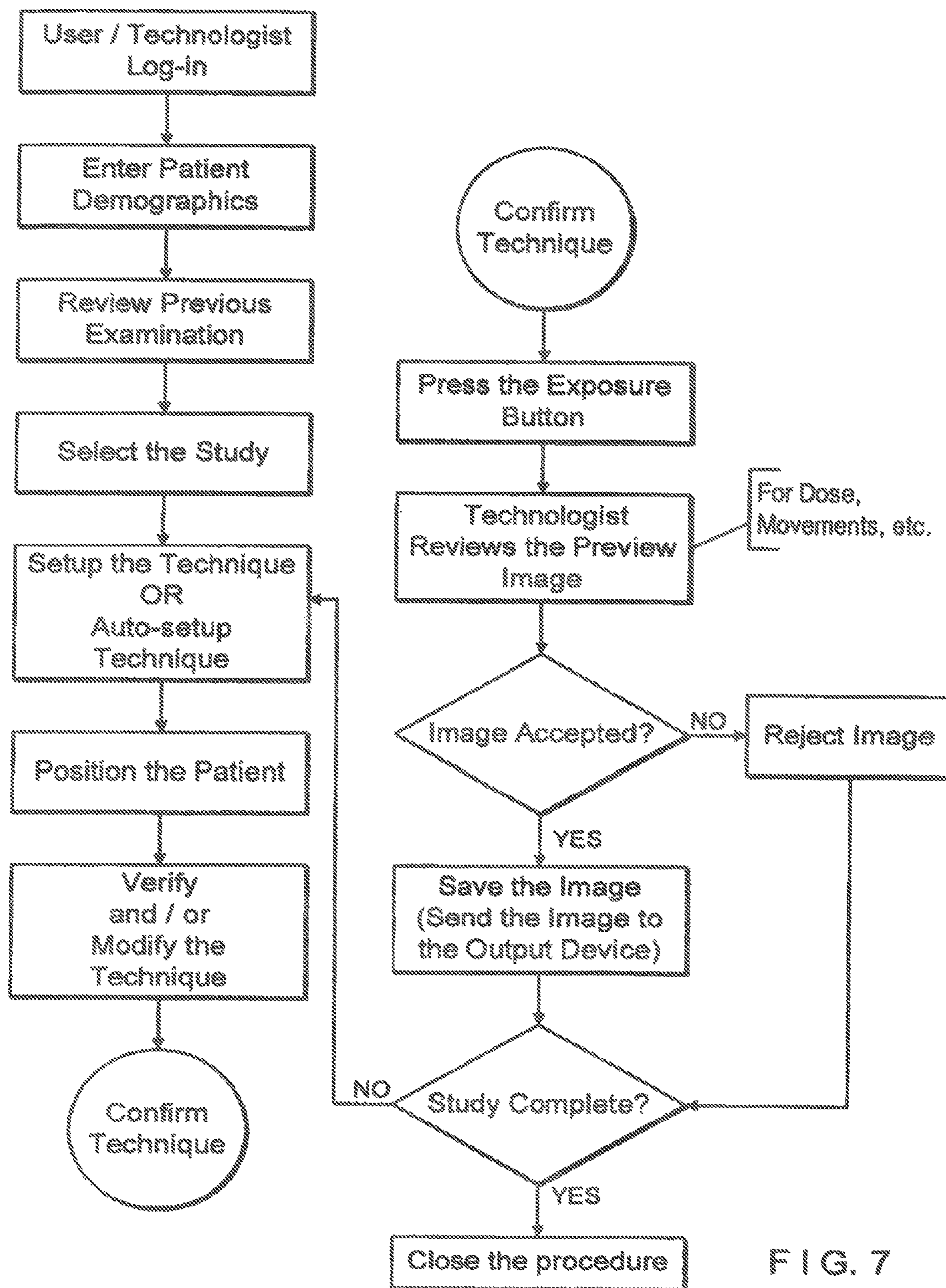


FIG. 7

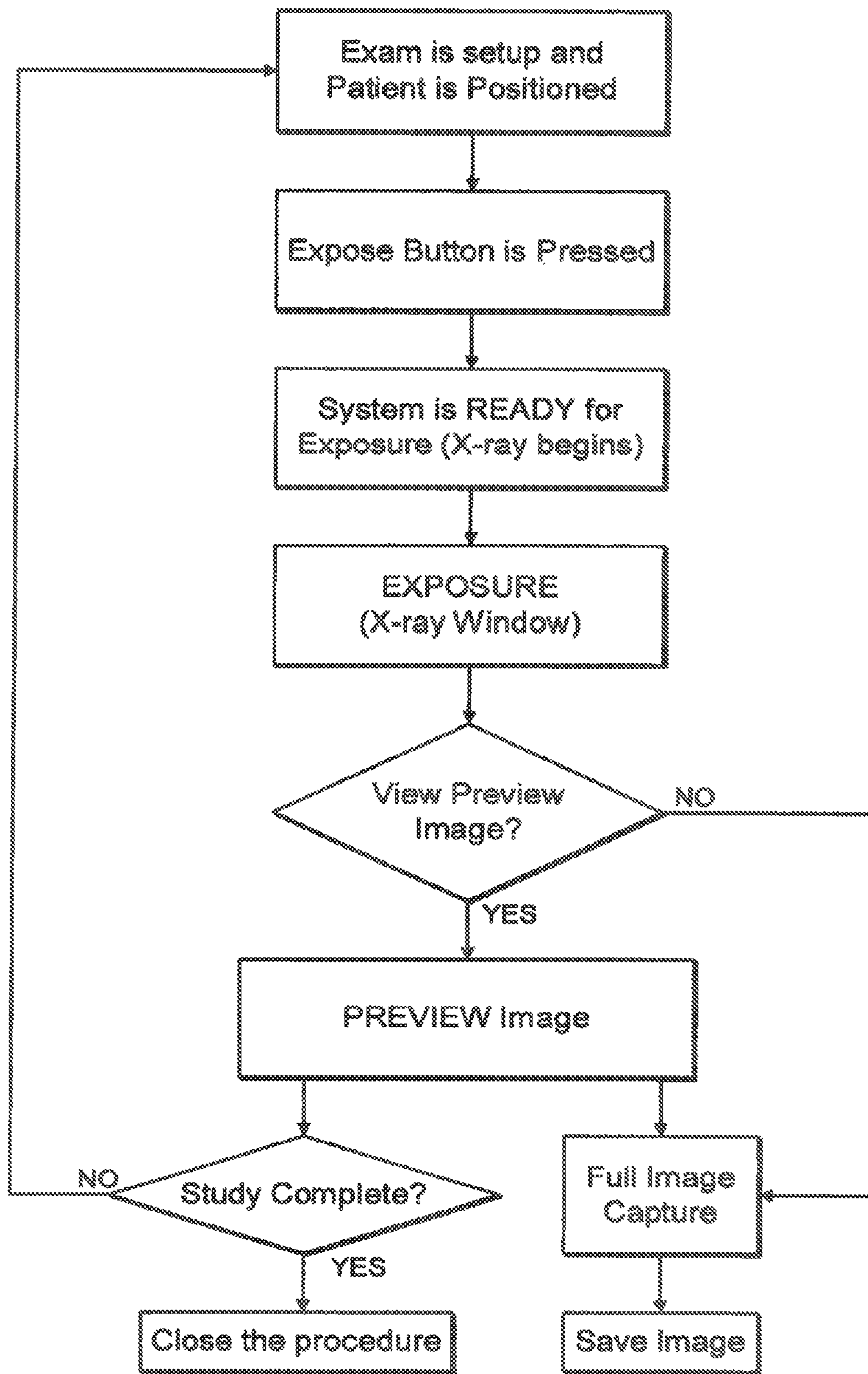


FIG. 8

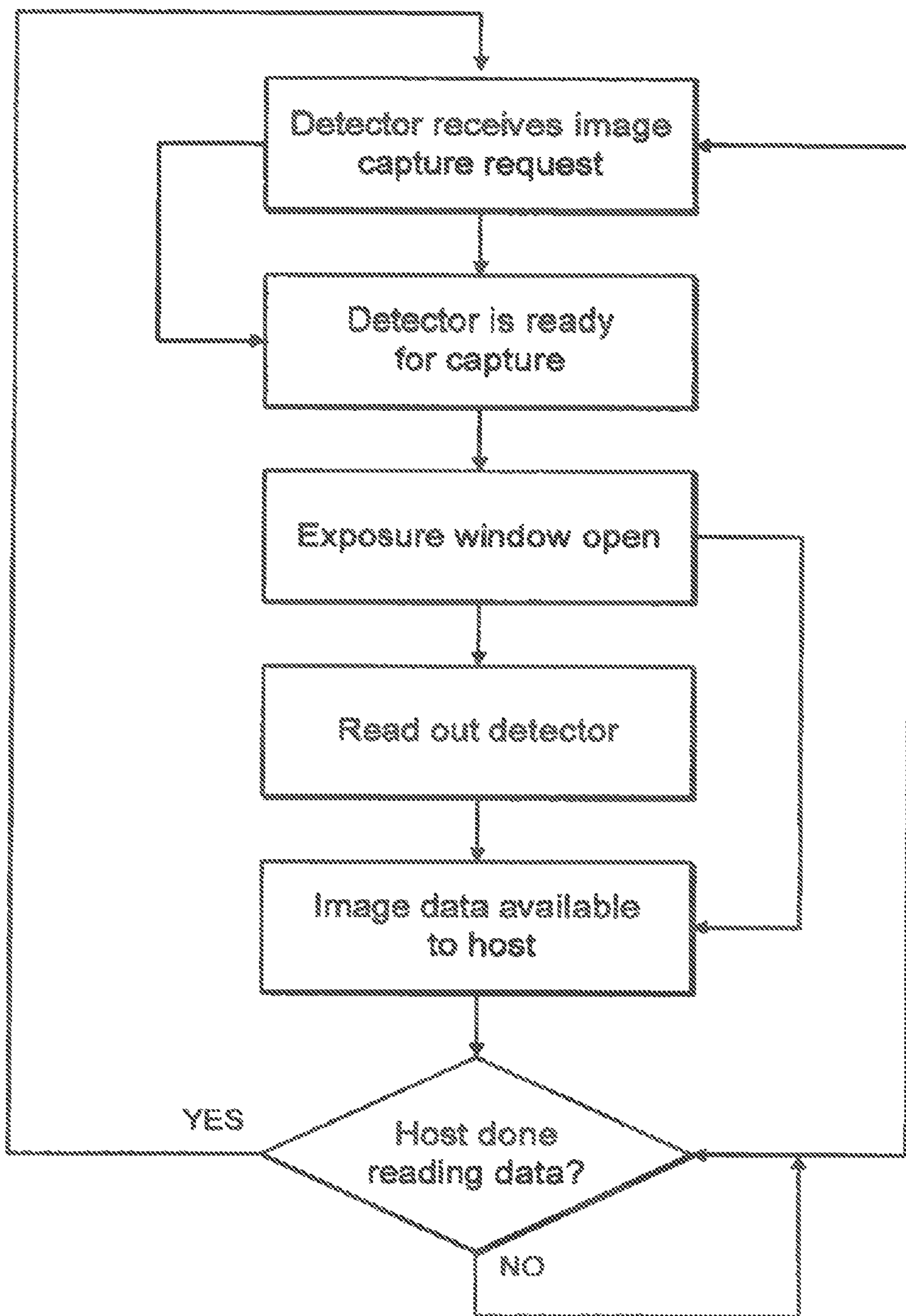


FIG. 9

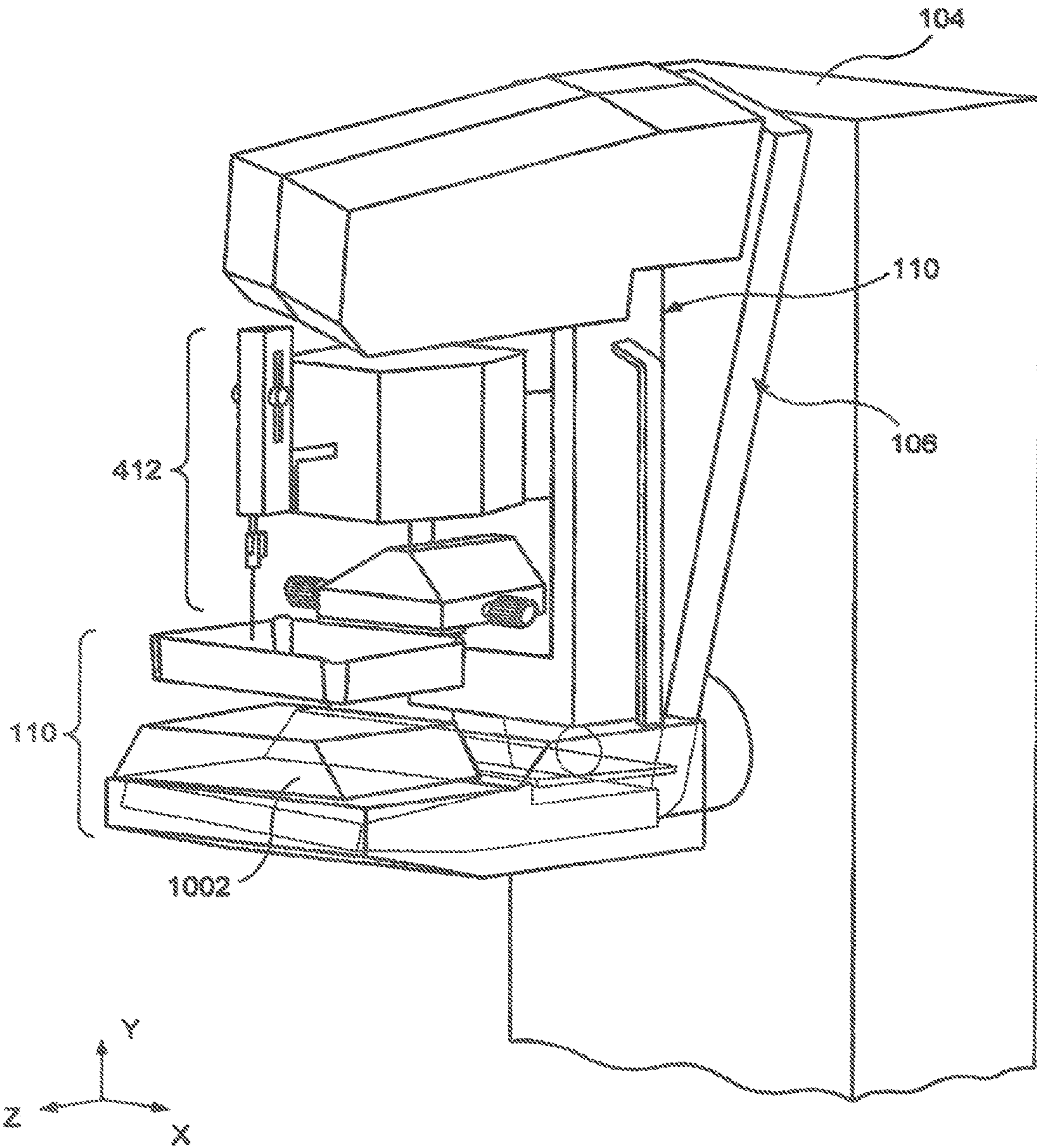


FIG. 10

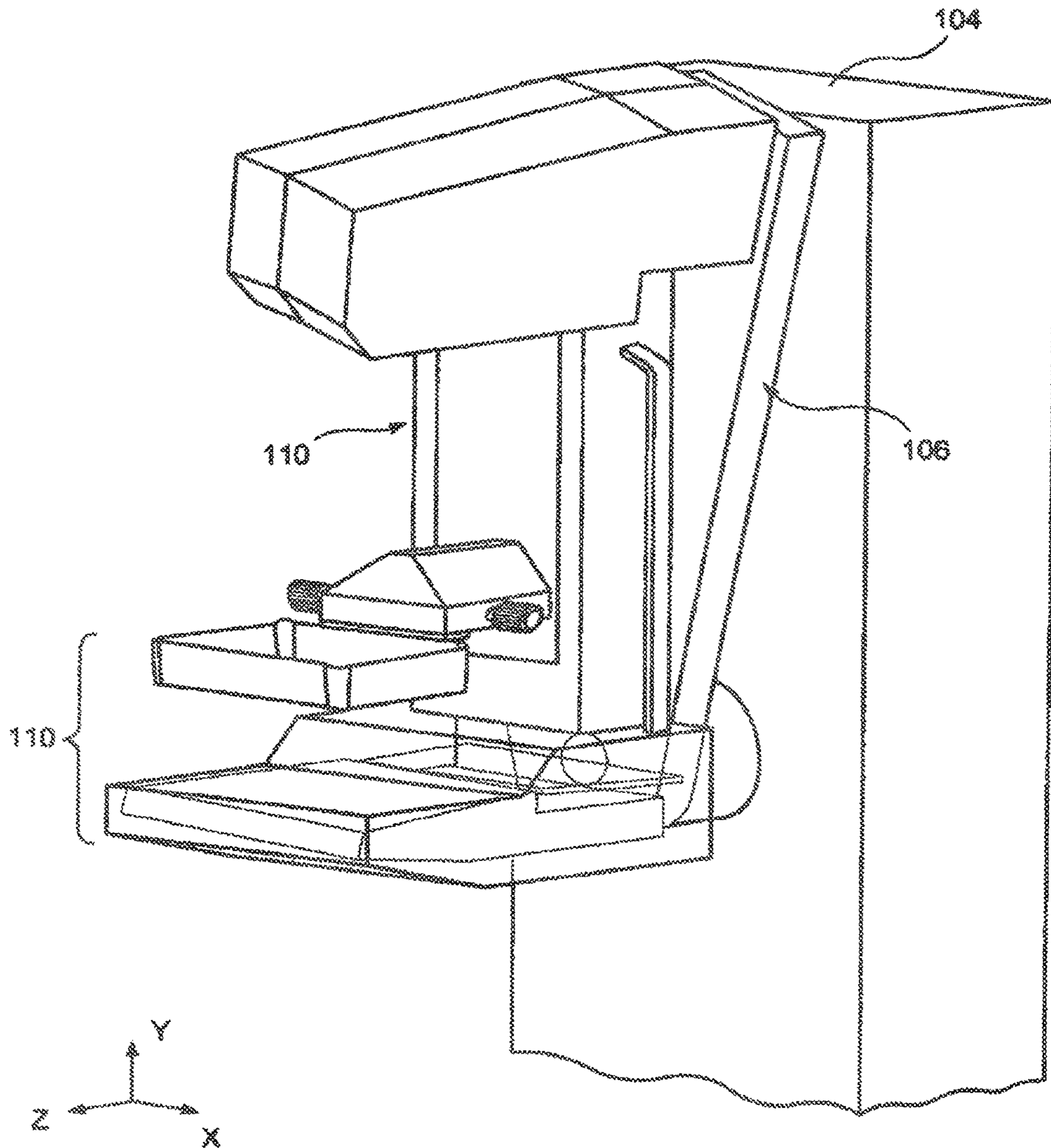
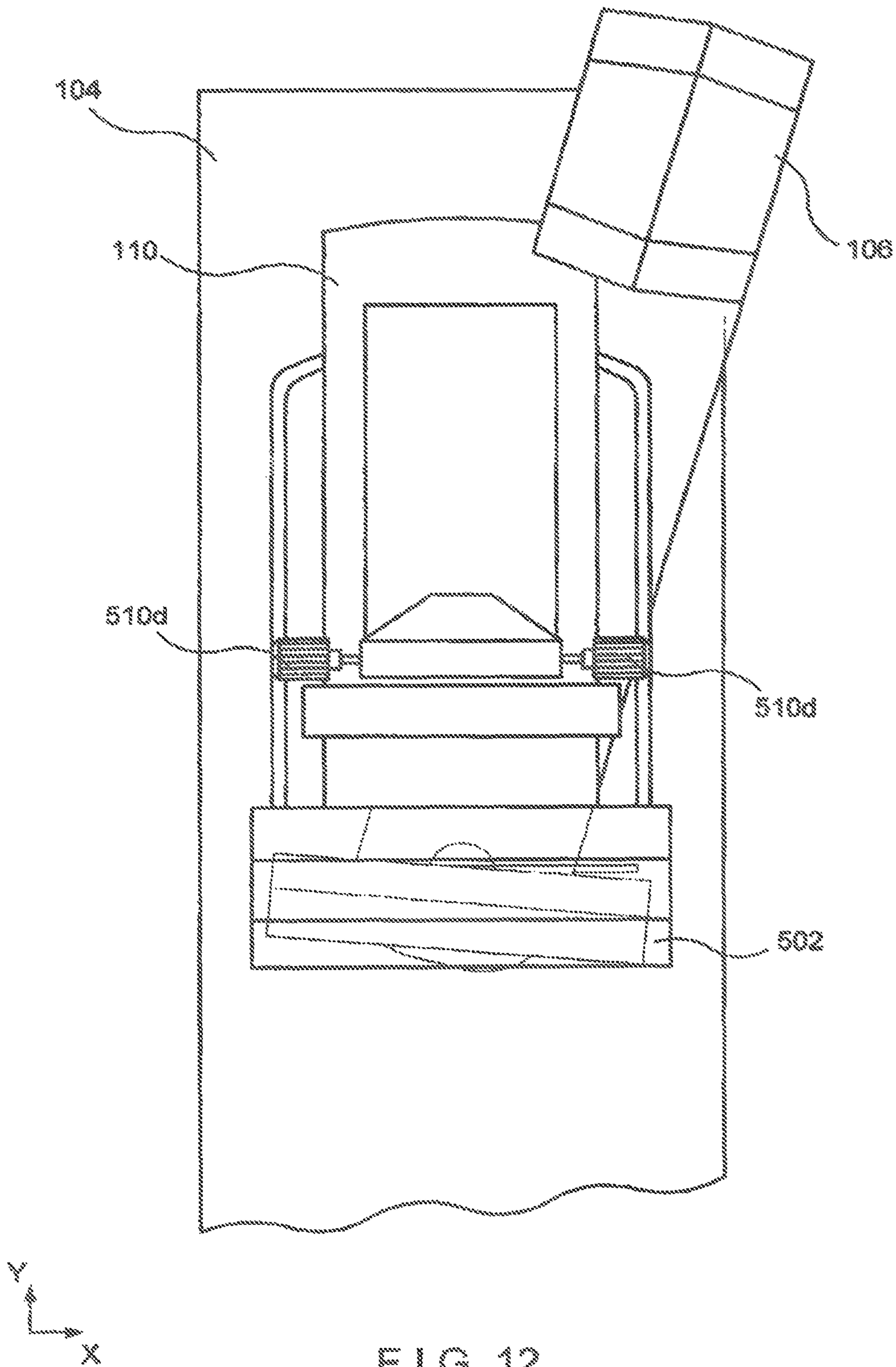


FIG. 11



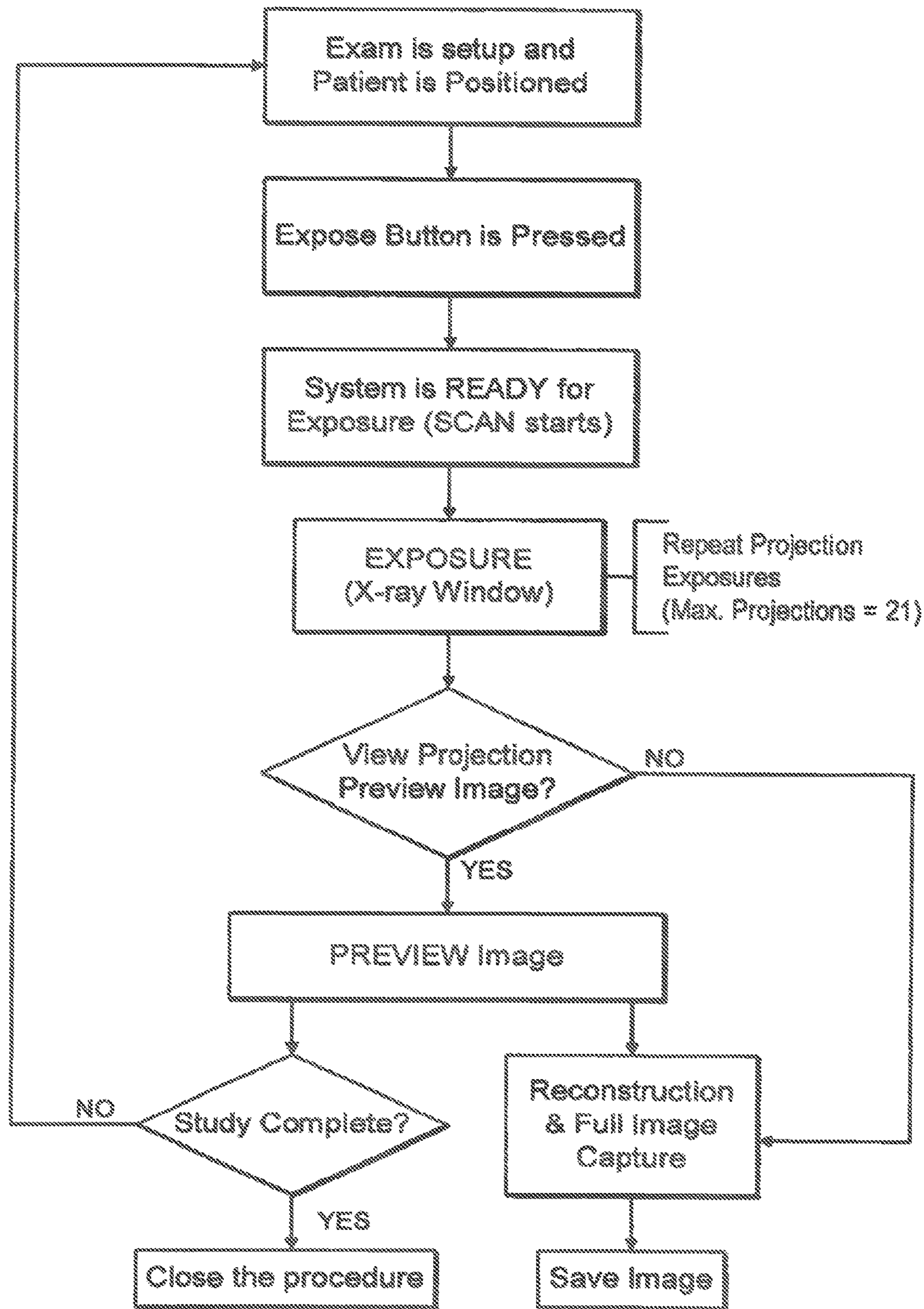


FIG. 13

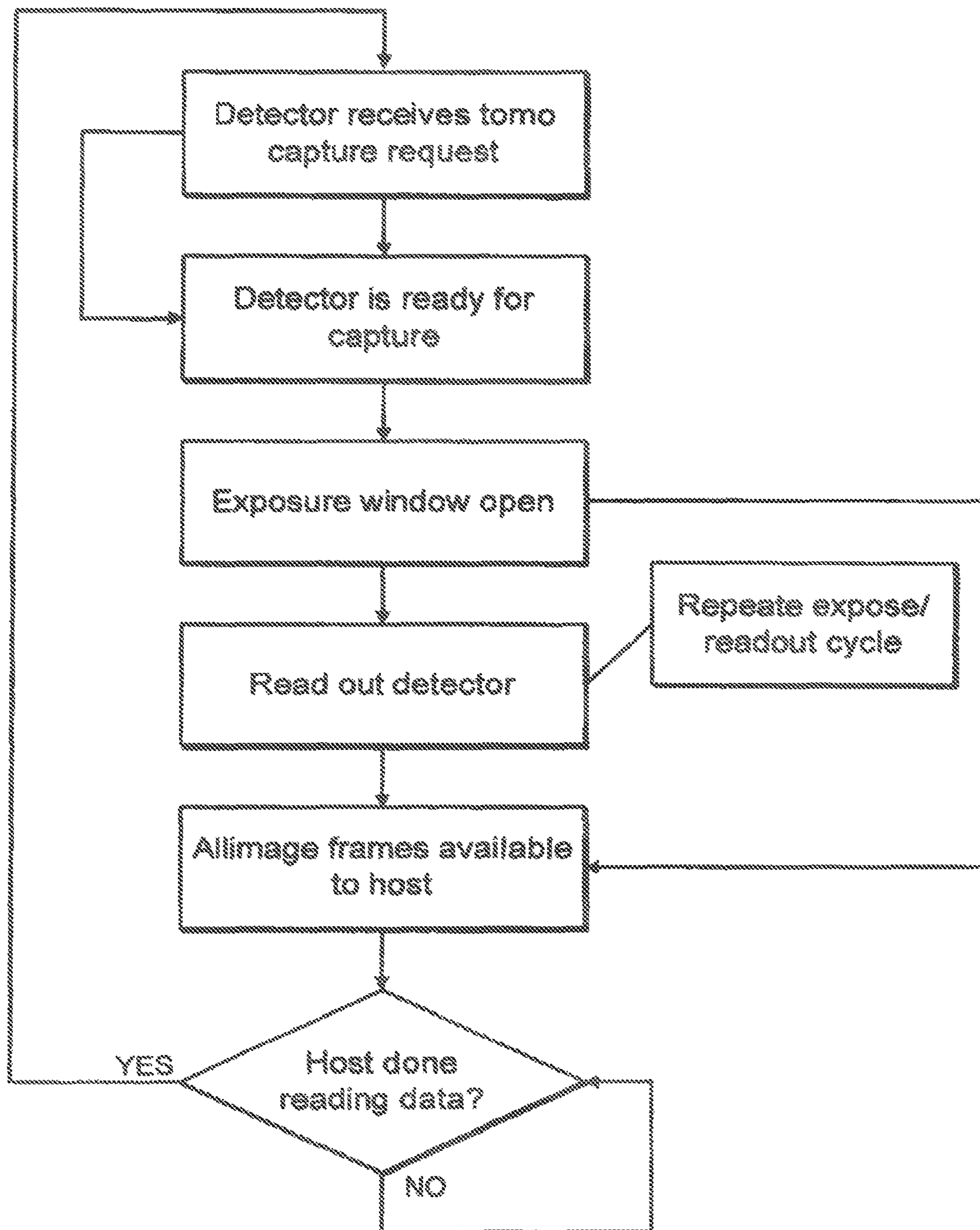


FIG. 14

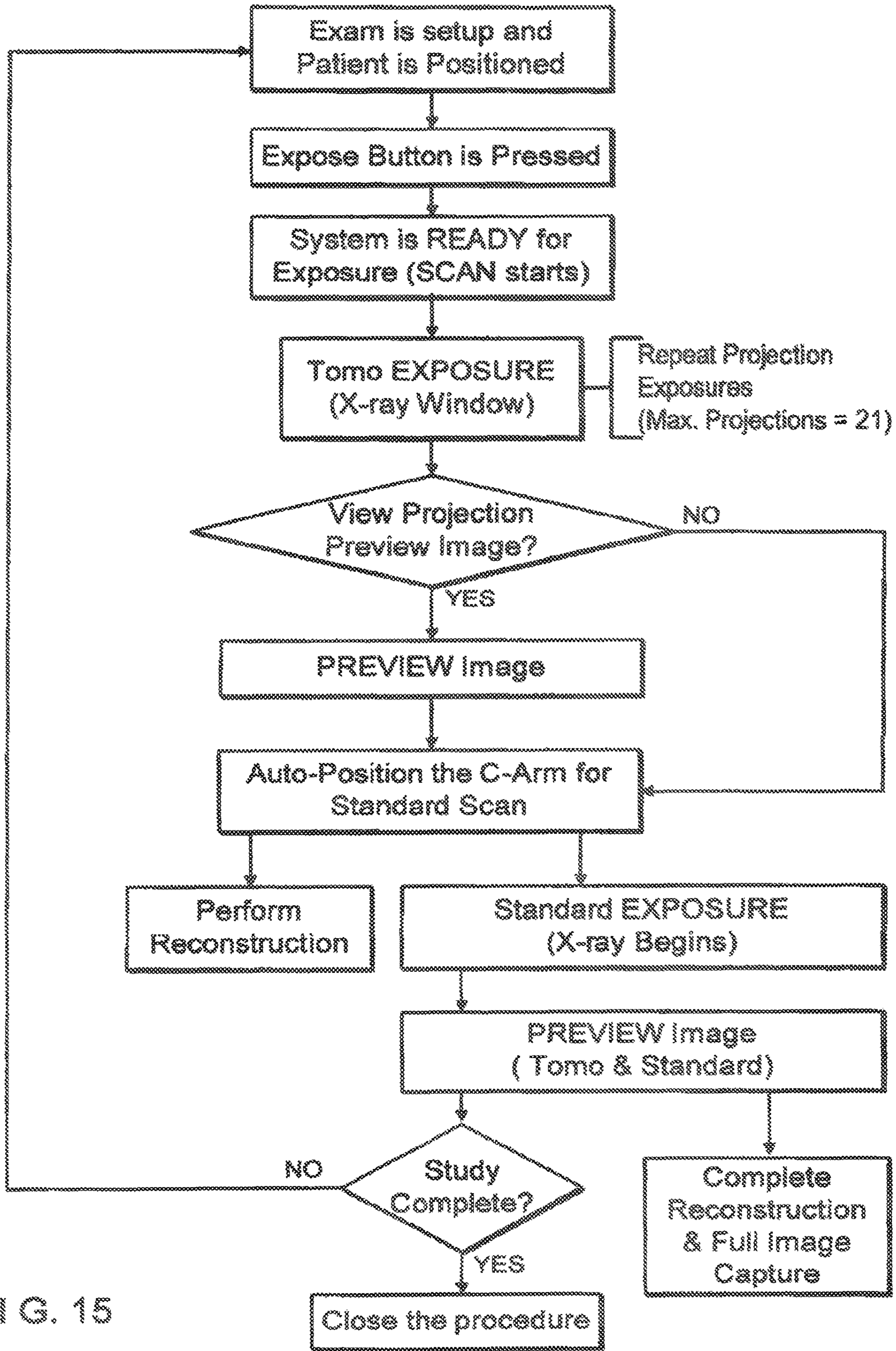


FIG. 15

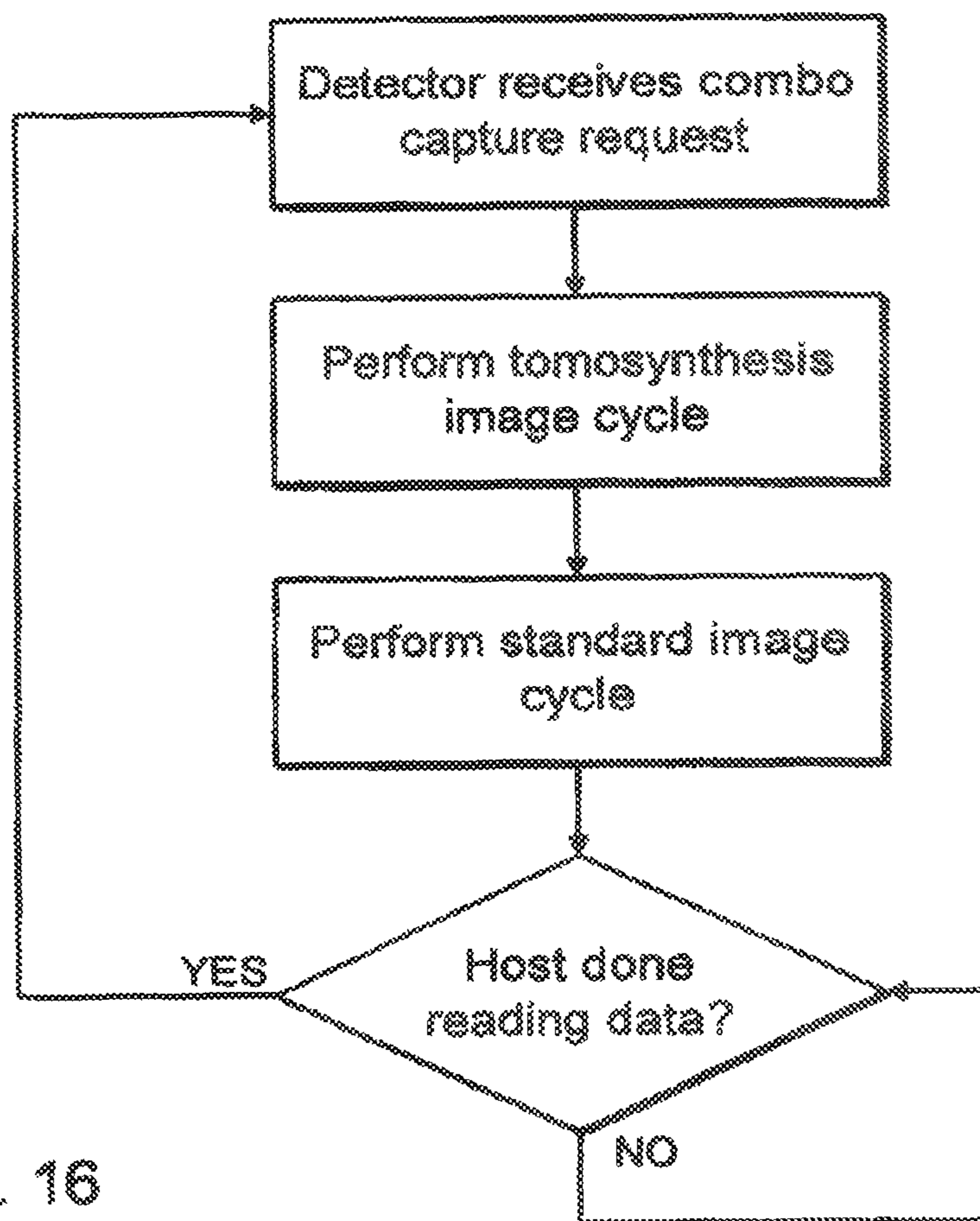


FIG. 16

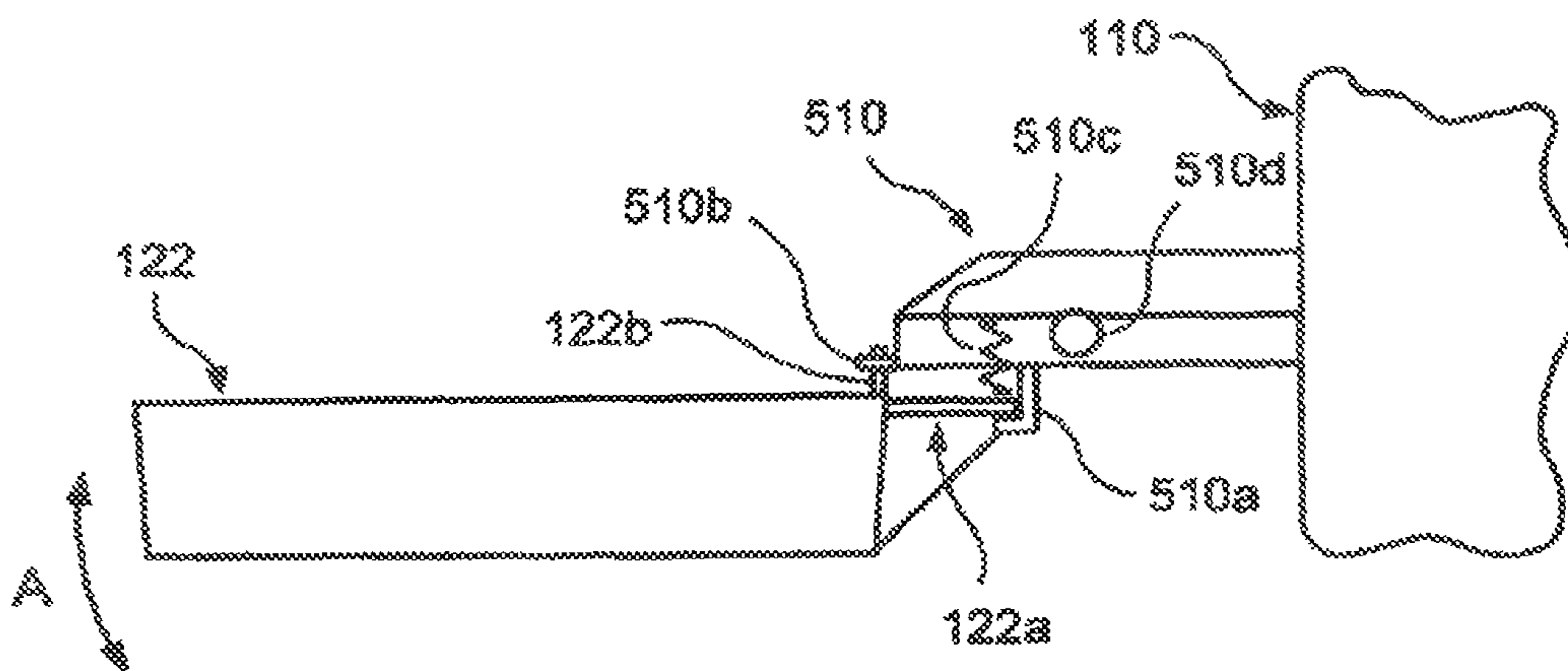


FIG. 17

1

**INTEGRATED MULTI-MODE
MAMMOGRAPHY/TOMOSYNTHESIS X-RAY
SYSTEM AND METHOD**

RELATED APPLICATION

This application is a continuation application and claims priority under 35 U.S.C. § 120 to U.S. patent application Ser. No. 14/498,476, filed Sep. 26, 2014, now U.S. Pat. No. 9,549,709; which is a continuation of U.S. patent application Ser. No. 14/058,385, filed Oct. 21, 2013, now U.S. Pat. No. 9,066,706; which is a continuation of U.S. patent application Ser. No. 13/462,342, filed May 2, 2012, now U.S. Pat. No. 8,565,374; which is a continuation of U.S. patent application Ser. No. 12/954,971, filed Nov. 29, 2010, now U.S. Pat. No. 8,175,219; which is a continuation of U.S. patent application Ser. No. 11/791,601, filed Feb. 22, 2008, now U.S. Pat. No. 7,869,563; which is a national stage entry of PCT/US2005/042613, filed Nov. 23, 2005; which claims priority to and the benefit of U.S. provisional patent application No. 60/631,296, filed Nov. 26, 2004. Each of the above is incorporated by reference.

FIELD OF THE INVENTION

This patent specification pertains to x-ray mammography and, more specifically, to an integrated system for selectively carrying out x-ray mammography and/or tomosynthesis imaging and a method of using such a system.

BACKGROUND OF THE INVENTION

X-ray mammography has long been a screening modality for breast cancer and other lesions, and also has been relied on for diagnostic and other purposes. For many years, the breast image was recorded on x-ray film but more recently digital x-ray image receptors have come into use, as in the Selenia™ mammography system available from Hologic, Inc. of Bedford, Mass. and its division Lorad Corporation of Danbury, Conn. For mammograms, a cone-shaped or pyramid-shaped x-ray beam passes through the compressed breast and forms a two-dimensional projection image. Any one of a number of orientation can be used, such as cranial-caudal (CC) or MLO (mediolateral-oblique) orientation. More recently, breast x-ray tomosynthesis has been proposed. The technology typically involves taking two-dimensional (2D) projection images of the immobilized breast at each of a number of angles of the x-ray beam relative to the breast and processing the resulting x-ray measurements to reconstruct images of breast slices that typically are in planes transverse to the x-ray beam axis, such as parallel to the image plane of a mammogram of the same breast. The range of angles is substantially less than in computerized tomography, i.e., substantially less than 180°, e.g. ±15°. Tomosynthesis technology is described in U.S. patent application Ser. No. 10/723,486 filed Nov. 26, 2003; a prototype of a unit with at least some of the described features was shown at the 2003 Radiological Society of North America meeting in Chicago, Ill. Additional prototypes are in clinical testing in this country as of the filing of this patent specification. Other approaches to tomosynthesis also have been proposed: see, e.g., U.S. Pat. Nos. 4,496,557, 5,051,904, 5,359,637, 6,289,235, and 6,647,092, published U.S. Patent Applications Nos. 2001/0038861, 2004/066882, 2004/0066884, and 2004/0066904, and Digital Clinical Reports, Tomosynthesis (GE Brochure 98-5493, 11/98). How to reconstruct tomosynthesis images is discussed to

2

DG Grant, “Tomosynthesis: a three-dimensional imaging technique”, IEEE Trans. Biomed. Engineering, Vol BME-19, #1, (January 1972), pp 20-28. See, also, U.S. Provisional Application Ser. No. 60/628,516, filed Nov. 15, 2004, and entitled “Matching geometry generation and display of mammograms and tomosynthesis images”. Mammography systems can also be used in interventional procedures, such as biopsy, by adding a biopsy station (for example, the StereoLoc II™ Upright Stereotactic Breast Biopsy System, which is available from Hologic, Inc.). The patents, applications, brochures, and article cited above are hereby incorporated by reference in this patent specification as though fully set forth herein.

In clinical use, it can be desirable for a number of reasons to assess both tomosynthesis images and conventional mammograms of the patient’s breasts. For example, the decades of conventional mammograms have enabled medical professionals to develop valuable interpretation expertise. Mammograms may offer good visualization of microcalcifications, and can offer higher spatial resolution compared with tomosynthesis. Tomosynthesis images may have different desirable characteristics—e.g., they may offer better visualization of structures that can be obscured by overlying or underlying tissue in a conventional mammogram.

While the existing and proposed systems for x-ray mammography and tomosynthesis offer many advantages, it is believed that a need still exists for further improvements to make mammography/tomosynthesis more useful, and that it is particularly desirable to make it possible to use the same system in different modes of operation and thereby reduce acquisition and operating costs and provide greater clinical value and convenience.

SUMMARY

This patent specification describes examples of systems and methods for multi-mode breast x-ray imaging. A single system carries out breast imaging in modes that include standard mammography, diagnostic mammography, dynamic imaging such as with a contrast agent and at different x-ray energies, tomosynthesis imaging, combined standard and tomosynthesis imaging during a single breast compression, needle localization, and stereotactic imaging with a biopsy station mounted to the system.

In an example of a system using the teachings of this patent specification, a compression arm assembly for compressing and immobilizing the breast for x-ray imaging, an x-ray tube assembly, and an x-ray image receptor can be angled relative to each other for different imaging protocols and modes. They can be independently rotated and synchronized as needed, or can be mechanically linked for appropriate synchronized rotation. A patient shield can be mounted to the compression arm assembly to provide a mechanical interlock against patient contact with the rotating x-ray tube assembly. A fully retractable anti-scatter grid can be used that can cover the imaging area of the x-ray receptor in some modes but be retracted completely outside the imaging area for other modes.

The exemplify system further includes a breast compression paddle that is laterally movable, under manual control or when motorized and operating under software control. The compression paddle can shift automatically depending on the view to be acquired. For example, the paddle can be centered on the x-ray receptor for a CC view, shifted to one lateral side of the receptor an MLO view of one breast and to the other lateral side of the receptor for an MLO view of the other breast. The paddle can be automatically recognized

by the system when mounted so that the shifts can be adjusted to the type of paddle.

The compression paddle can be easily removable from a support that has a mechanism for laterally moving the paddle and for allowing the paddle to tilt for better conformance with the breast for selected image modes but looking the paddle against tilt for other modes. With the movement mechanism in the support and not integral with the paddle, the paddle can be simple and inexpensive, and easy to mount to and remove from the support. A number of relatively inexpensive paddles of different sizes and shapes can be provided and conveniently interchanged to suit different procedures and patients.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a perspective view of a gantry and an acquisition workstation in accordance with an example of the disclosed system.

FIG. 2 is an enlarged view of a portion of the system of FIG. 1, with a tube arm assembly in a rotated position.

FIG. 3 is a front elevation of the apparatus of FIG. 2.

FIG. 4 is side view of a gantry with a biopsy station and a spacer with schematic illustration of other mechanisms.

FIG. 5 is an enlarged view of a portion of FIG. 1.

FIG. 6 is a block diagram of the disclosed system when connected to other systems.

FIG. 7 is a flow chart illustrating a general work flow for the disclosed system.

FIG. 8 is a flow chart illustrating one of several examples of work flow for a standard mammography mode.

FIG. 9 is a flow chart illustrating one of several examples of work flow for an image detector subsystem in the standard mammography mode.

FIG. 10 is a perspective view of the structure of FIG. 4.

FIG. 11 is similar to FIG. 2 but shows a tube arm assembly angled differently.

FIG. 12 is a front elevation of the structure of FIG. 11.

FIG. 13 is a flow chart illustrating one of several examples of work flow for a tomosynthesis mode.

FIG. 14 is a flow chart illustrating one of several examples of work flow for an image detector subsystem in the tomosynthesis mode.

FIG. 15 is a flow chart illustrating one of several examples of work flow for a combination mode.

FIG. 16 is a flow chart illustrating one of several examples of work flow for an image detector subsystem in the combination mode.

FIG. 17 is an enlarged side view of a structure for removably mounting a breast compression paddle.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In describing examples and preferred embodiments illustrated in the drawings, specific terminology is employed for the sake of clarity. However, the disclosure of this patent specification is not intended to be limited to the specific terminology so selected and it is to be understood that each specific element includes all technical equivalents that operate in a similar manner.

FIG. 1-6 illustrate a non-limiting example of a multi-mode mammography/tomosynthesis system comprising a gantry 100 and a data acquisition work-station 102. Gantry 100 includes a housing 104 supporting a tube arm assembly 106 rotatably mounted thereon to pivot about a horizontal axis 402 (FIG. 4) and carrying an x-ray tube assembly 108.

X-ray tube assembly 108 includes (1) an x-ray tube generating x-ray energy in a selected range, such as 20-50 kV, at mAs such as in the range 3-400 mAs, with focal spots such as a nominal size 0.3 mm large spot and nominal size 0.1 mm small spot (2) supports for multiple filters such as molybdenum, rhodium, aluminum, copper, and tin filters, and (3) so adjustable collimation assembly selectively collimating the x-ray beam from the focal spot in a range such as from 7×8 cm to 24×29 when measured at the image plane of an x-ray image receptor included in the system, at a maximum source-image distance such as 75 cm. Also mounted on housing 104, for rotation about the same axis 402, is a compression arm assembly 110 that comprises a compression plate 122 and a receptor housing 114 having an upper surface 116 serving as a breast plate and enclosing a detector subsystem system 117 comprising a first panel x-ray receptor 502 (FIG. 5), a retractable anti-scatter grid 504 and a mechanism 506 for driving and retracting anti-scatter grid 504. Housing 104 also encloses the following components schematically illustrated in FIG. 4: a vertical travel assembly 404 for moving tube arm assembly 106 and compression arm assembly 110 up and down to accommodate a particular patient or imaging position, a tube arm assembly rotation mechanism 400 to rotate tube arm assembly 106 about axis 402 for different imaging positions, a detector subsystem rotation mechanism 408 for rotating components of detector subsystem 117 (such as x-ray receptor 502) about axis 402 to accommodate different operations modes, and couple/uncouple mechanism 410 to selectively couple or uncouple tube arm assembly 106 and compression arm assembly 110 to and from each other, and tube arm assembly 106 and detector subsystem 117 to and from each other. Housing 104 also encloses suitable motors and electrical and mechanical components and connections to implement the functions discussed here. A patient shield 200, schematically illustrated in FIG. 2, can be secured to compression arm assembly 110 to provide a mechanical interlock against patient contact with the rotating x-ray tube arm assembly 106. Work-station 102 comprises components similar to those in the Selenia™ mammography system, including a display screen (typically a flat panel display that may include touch-screen functionality), user interlace devices such as a keyboard, possibly a touch-screen, and a mouse or trackball, and various switches and indicator lights and/or displays. Work-station 102 also includes compute facilities similar to those of the Selenia™ system (but adapted through hardware, firmware and software differences) for controlling gantry 100 and for processing, storing and displaying data received from gantry 100. A power generation facility for x-ray tube assembly 108 may be included in housing 104 or in work-station 102. A power source 118 powers work-station 102. Gantry 100 and work-station 102 exchange data and controls over a schematically illustrated connection 120.

As illustrated in FIG. 6, additional storage facilities 602 can be connected to work-station 102, such as one or more optical disc drives for storing information such as images and/or for providing information to work-station 102 such as previously obtained images and software, or a local printer (not shown). In addition, the disclosed system can be connected to a hospital or local area or other network 604, and through the network to other systems such as a soft copy workstation 606, a CAD (Computer Aided Detection) station 608 for computer-processing mammography and/or tomosynthesis images to identify likely abnormalities, an image printer 610 for printing images, a technologist workstation 612, other imaging systems 614 such as other mammography systems or systems for other modalities for

exchange of images and/or other information, and to a PACS (Picture Archiving) systems **616** for archiving images and other information and/or retrieving images and other information.

The illustrated system has several modes of operation. An example of typical workflow generally applicable for each mode is illustrated in FIG. 7, and several examples of operational modes are discussed below. Of course, this is only one example and workflow steps may be arranged differently. In all modes, the operator can perform x-ray exposure using manual setting of technic factors such as mA and mSec, or can use an automatic exposure control as known in the art to set the exposure time, kV and filter modes for an image, for example by using a short, low-x-ray dose pre-exposure. Workstation **102** is set up to record the exposure technic information and associate it with the breast image for later review.

In standard mammography mode, typically used for screening mammography, tube arm assembly **106** and compression arm assembly **110** are coupled and locked together by **410** in a relative position such as seen in FIG. 1, such that an x-ray beam from x-ray tube assembly **108** illuminate x-ray receptor **502** when the patient's breast is compressed by compression device **112**. In this mode, the system operates in a manner similar to said Selenia™ system to take a mammogram. Vertical travel assembly **404** and tube arm rotation mechanism **406** can make vertical adjustments to accommodate a patient, and can rotate tube arm assembly **106** and compression arm assembly **118** together as a unit about axis **402** for different image orientations such as for CC and for MLO images. For example, tube arm assembly **106** and compression arm assembly **110** can rotate between (-195°) and ($+150^\circ$) about axis **402**. As in the Selenia™ system, compression device **112** includes a compression paddle **122** that can move laterally, in a direction along the chest wall of a patient, to adjust for different imaging orientations. However, as described further below, the mechanism for supporting and moving compression paddle **122** is different. Typically, anti-scatter grid **504** is over x-ray receptor **502** in the standard mammography mode to reduce the effect of x-ray scatter. FIG. 8 illustrates a typical workflow for an exposure in standard mammography mode, and FIG. 10 illustrates an example of the operation of detector subsystem **117** in standard mammography. Of course, these are only examples; other workflow steps or orders of steps can be used instead.

In a diagnostic mode, the patient's breast can be spaced from upper surface **116**, for example by an x-ray translucent spacer gantry **1002** (FIG. 10), with the system otherwise similar to FIG. 1, for a magnification of up to 1.8, for example. In this mode, as in standard mammography, tube arm assembly **106** and compression arm assembly **110** are locked to each other and can move up or down and rotate about axis **402** for different image orientation. A different spacer **1002** can be used for a different degree of magnification. Also, differently shaped or dimensioned compression paddles **122** can be used for different breast compression effects. The x-ray tube in x-ray tube assembly **108** can be set to a smaller focal spot size to improve a diagnostic image. In this mode, anti-scatter grid **504** typically is retracted when magnification is used such that grid **504** is completely out of the image. The user can elect not to use a spacer **1002** in diagnostic imaging, in which case anti-scatter grid **504** can be used over the entire image.

In a dynamic imaging mode, a number of breast images are taken while the patient's breast remains compressed. In one technique, an agent such as iodine is injected into the

patient and after a suitable waiting time such as about one minute for a maximum uptake, two images breast are taken in rapid succession, for example one at an x-ray energy just above the K-edge of iodine and one at an energy just below the K-edge. Alternatively, a succession of breast images can be taken at a single x-ray energy band or bands just above and below the K-edge or at another x-ray energy range, to track the uptake of agent over time. Another technique adds taking a baseline breast image before or soon after injecting the agent and using it together with later breast images to generate subtraction images that provide better visualization of anatomy that may be of interest. Still another dynamic imaging mode technique comprises injecting a contrast agent and taking a succession of images over a period such as 5-7 minutes, for example one image every minute, and processing the image data to generate for each pixel, or at least for each pixel of interest, a histogram of the change in the pixel value, to thereby use the manner in which pixel values change to differential abnormal tissue. For this mode, work-station **102** can store preset data that commands gantry **100** and work-station **102** to take a desired sequence of images for the dynamic mode technique selected by the operator, such that the command data sets the appropriate parameters such as x-ray energy, dose, timing of images, etc. Alternatively, such processing to assess changes in pixel values can be done for a region of interest rather than over individual pixels, to produce information such as a measure of changes in the average pixel values in the region of interest.

In tomosynthesis mode, tube arm assembly **106** and compression arm assembly **110** are decoupled by unit **410** such that compression arm assembly **110** stays in one position, compressing the patient's breast, while tube arm assembly **106** rotates about axis **402**, for example between the position illustrated in FIG. 2 to that illustrated in FIG. 11, or $\pm 15^\circ$ relative to compression arm assembly **110**. Tomosynthesis can be carried out for different image orientations, so that compression arm assembly **110** can be rotated about axis **402** (alone or together with assembly **106**) for a desired image orientation and locked in place, and then tube arm assembly **106** can be rotated relative to that position of compression arm assembly **110** for tomosynthesis imaging over $\pm 15^\circ$ or some other desired angular range. In one example, 11 images are taken during an angular sweep of tube arm assembly **106**, one every approximately 3° . However, a different number of images can be taken, for example up to 21 during a single sweep. For tomosynthesis images, the x-ray tube in x-ray tube assembly **108** continuously rotates and the x-ray tube is pulsed for each image, for example, for x-ray energy pulses each lasting approximately 100 mSec, although pulses of different duration can be selected. Alternatively, the rotational motion can stop for taking each image, or continuous motion without pulsing can be used (and the timing of data measurements relied to define pixel values). As seen in FIGS. 2, 3, 5, 11 and 12, in this mode mechanism **506** fully retracts anti-scatter grid **504** away from x-ray receptor **502** so grid **504** is out of the image. Also as seen in these FIGS., while the breast remains immobilized in compression arm assembly **110** during the angular sweep of tube arm assembly **106**, x-ray receptor **502** rocks within receptor housing **114**. In this rocking motion, controlled by unit **401** (FIG. 4), a line normal to the image face of x-ray receptor **502** may keep pointing to the focal spot of the x-ray tube in x-ray tube assembly **108**. Alternatively, the rotation of tube arm assembly **106** and rocking of x-ray receptor **502** can be through different angles; for example, tube arm assembly **106** can rotate through 15°

while x-ray receptor **502** rocks through 5° , i.e., the rocking angle can be amount one-third that of assembly **108**. Synchronous rotation of tube arm assembly **106** and rocking of x-ray receptor **502** can be achieved by controlling separate motors for each or, alternatively, through using a motor to drive tube arm assembly **106** and a mechanical coupling between the rotation of tube arm assembly **106** and rocking of x-ray receptor **502**. Image data can be obtained and processed into tomosynthesis images for display and/or storage as described in the material incorporated by reference, for example in co-pending patent application Ser. No. 10/723,486 or in U.S. Provisional Application No. 60/621,516, filed Nov. 15, 2004. FIG. **13** illustrates a typical workflow for tomosynthesis mode operation, and FIG. **14** illustrates an example of the operation of detector subsystem **117** in that mode. Again, these are only examples, and other steps or orders of steps can be used instead.

In a combination mode, during a single compression of the patient's breast the system takes a conventional mammogram and tomosynthesis images. In this mode, while the breast remains compressed in compression arm assembly **110**, (1) tube arm assembly **106** sweeps and x-ray receptor **502** rocks, each through an appropriate angle, and exposures are taken for tomosynthesis images, and (2) a standard mammogram is taken. The standard mammogram can be taken at a 0° relative angle between tube arm assembly **106** and a normal to the imaging plane of x-ray receptor **502**, and can be taken before or after the tomosynthesis images are taken or between the taking of two successive tomosynthesis images. Typically, each tomosynthesis image utilizes substantially lower x-ray dose than the standard mammogram. For example, the total x-ray dosage for tomosynthesis imaging in one sweep of tube arm assembly **106** can be approximately the same as that for a single standard mammogram, or up to approximately three times that dosage. The relationship between the two dosages can be user-selected. FIG. **15** illustrates an example of workflow for the combination mode, and FIG. **16** illustrates an example of the operation of detector subsystem **117** in that mode. Again, these are examples, and different steps or orders of steps can be used instead. For example, a preferred approach may be to take the standard mammogram first, then move arm **106** to one end of its rotational range for tomosynthesis and take the tomosynthesis images. The order in which the two types of images are taken may be optimized such that the overall imaging time is minimized, and an order that achieves such minimization can be the preferred order. The exposure (tube current mA, tube voltage kVp, and exposure length msec) techniques for the standard mammogram and the tomosynthesis exposures can be set manually, or by using automatic methods. If the standard mammogram is taken first, its exposure techniques can be used to set an optimal technique for the subsequent tomosynthesis images, and vice versa. The exposure technique can be modified dynamically, if the software senses that the signal reaching the image receptor is either too low or too high and adjust subsequent exposures as needed.

In a stereotactic mode, during a single compression of the patient's breast at least two images of taken, for example one at $(+15^\circ)$ angle and at (-15°) angle of tube arm assembly **106** relative to compression arm assembly **110**, although other angles can be used and more images can be taken. X-ray receptor **502** can remain in place for this procedure, or can be rocked through a selected angle, for example through an angle sufficient to maintain the same orientation of the imaging surface of receptor relative to tube arm assembly **106**. A spacer **1002** can be used for magnification. If x-ray

receptor **502** remains in plane despite rotation of arm **106**, or if spacer **1002** is used, anti-scatter grid **504** is fully retracted; if x-ray receptor **502** maintains its orientation relative to tube arm assembly **106** and not spacer **1002** is used, anti-scatter grid **504** need not be retracted. As is known in the art, the two or more images can be used to identify the location of a lesion, so that needle biopsy can be used, for example with an upright needle biopsy station **412** (FIG. **4**) in a manner similar to that used with the commercially available Selenia™ system and StereoLoc II™. A compression paddle **122** appropriate for needle biopsy typically is used when taking the stereotactic images. Alternatively, some or all of the images taken in the tomosynthesis mode and/or in the combined mode can be used to identify the location of a lesion for biopsy, in which case a compression paddle **122** appropriate for the purpose typically is used when taking the images.

In needle localization mode, x-ray images can be taken after a biopsy or other needle is inserted into the compressed breast. For this purpose, imaging such as in the stereotactic mode, the tomosynthesis mode, or the combined mode can be used.

In the disclosed system, compression paddle **122** is movable laterally, as generally described in U.S. Patent Application Publication No. 2005/0063509 A1, hereby incorporated by reference herein. In addition, compression paddle **122** can pivot about an axis along the patient's chest wall to conform the breast shape in certain procedures, as discussed in said U.S. Pat. No. 5,786,327. However, in the system of this patent specification compression paddle **122** is mounted differently and moves in a different manner.

As illustrated in FIGS. **5** and **17**, compression paddle **122** is removably mounted to a support **510** that moves up and down compression arm assembly **110** as needed for breast compression. To mount compression paddle **122** onto **510**, a projection compression paddle **122a** of the paddle engages a projection **510a** of the support, and a projection **122b** of the paddle latches onto projection **510b** of the support. Projection **510a** is spring-loaded, such as by a spring schematically illustrates at **510c** to allow for pivoting compression paddle **122** about an axis where it latches onto **510**, as illustrated by arrow A, for better conformance with the compressed breast in some imaging protocols. Other imaging protocols may require compression paddle **122** not to pivot, in which case projection **310a** is locked in place by a locking mechanism in **510** (not shows) to keep compression paddle **122** in place relative to support **510**. The locking mechanism can be manually set to a lock position, and manually unlocked by the operator. Alternatively, the locking mechanism can be controlled through an operator input at gantry **100** or workstation **102**. A sensing mechanism can be included to sense whether compression paddle **122** is locked against pivoting, to provide information that work-station **102** can use for setting imaging protocols such as for automated breast compression and automated exposure methods. Two knobs **510d**, one on each lateral side of support **510**, can be manually rotated to move projection **510b** and thus compression paddle **122** laterally such that it compress a breast that is not centered laterally on upper surface **116**, for example for MLO imaging. Each knob **510d** can operate a mechanism such as an endless screw rotating in a nut secured to projection **510b**. Alternatively, or in addition, projection **510b** and thus compression paddle **122** can be driven laterally by a motor, under control of operator switches or other interface at gantry **100** or at work-station **102**, or automatically positioned laterally under computer control.

Importantly, compression paddle **122** is driven for lateral movement by components that are a part of support **510**. Thus, compression paddle **122** can be simple structure, and can even be disposable, with a new one used for each patient or for only a few patients. This can simplify and reduce the cost of using the system, because an imaging facility usually stocks a number of different paddles for different purposes. If the lateral movement mechanism is integral with a compression paddle, the paddle assembly is considerably larger, heavier and more expensive. But with a compression paddle **122** that relies for lateral movement on support **510**, and is easily mounted by hand and without tools to support **510**, by sliding compression paddle **122a** into projection **510a** and latching projection paddle **122b** onto projection **510b**, and is easily removed by reversing the process, the expense of keeping a number of different compression paddles in stock or replacing paddles with new ones is greatly reduced, as are the time and convenience when changing from one type of compression paddle to another. Compression paddle **122** can include a bar code that is automatically read by a bar code reader in support **510**, to keep work-station **102** informed of the paddle currently mounted to support **510**, for use in automating imaging protocols. For example, the bar code information can be checked to ensure through computer processing that the type of paddle that is currently mounted on support **510** matches the imaging that will be commanded, and the information from the sensor for whether compression paddle **122** is locked in non-tilting mode can be used to automatically make adjustments for compression height to ensure accurate automatic x-ray exposure operation. Further, the bar code information identifying the paddle can be used to automatically set collimation in x-ray tube assembly **108** so that the x-ray beam matches the size and shape of the currently installed compression paddle **122**.

The above specific examples and embodiments are illustrative, and many variations can be introduced on these examples and embodiments without departing from the spirit of the disclosure or from the scope of the appended claims. For example, elements and/or features of different illustrative embodiments may be combined with each other and/or substituted for each other within the scope of this disclosure and appended claims.

This application claims the benefit of U.S. provisional application Ser. No. 60/631,296, filed Nov. 26, 2004 and entitled "INTEGRATED MULTI-MODE MAMMOGRAPHY/TOMOSYNTHESIS X-RAY SYSTEM AND METHOD", the entire contents of which are incorporated herein by reference.

The invention claimed is:

1. A system for multi-mode breast x-ray imaging comprising:

a compression arm assembly for compressing a patient's breast for x-ray imaging;
 an x-ray image receptor;
 an x-ray tube assembly, wherein the compression arm assembly, the x-ray tube assembly, and the x-ray image receptor are configured for movement about an axis to accommodate a plurality of imaging modes, and wherein the x-ray tube assembly is configured to rotate relative to the compression arm for at least a tomosynthesis imaging mode of the plurality of imaging modes; and

a patient shield secured to the compression arm assembly and spaced apart from the x-ray tube assembly, wherein during the tomosynthesis imaging mode the x-ray tube assembly is configured to rotate relative to at least a portion of the patient shield.

2. The system of claim **1**, wherein the patient shield is configured to provide a mechanical interlock against patient contact with the rotating x-ray tube assembly.

3. The system of claim **1**, wherein at least two of the plurality of imaging modes utilize a single breast compression.

4. The system of claim **3**, wherein the plurality of imaging modes comprise a mammography imaging mode and the tomosynthesis imaging mode.

5. The system of claim **1**, wherein the x-ray tube assembly moves continuously for image acquisition when the x-ray tube assembly rotates relative to the compression arm for at least one of the plurality of imaging modes.

6. The system of claim **1** further comprising an anti-scatter grid disposed adjacent to the x-ray image receptor for at least one of the plurality of imaging modes.

7. The system of claim **6**, wherein the anti-scatter grid is retractable out of an imaging area for at least one of the plurality of imaging modes.

8. The system of claim **1**, wherein the compression arm assembly comprises a breast compression paddle, wherein the breast compression paddle is configured to move laterally relative to the x-ray image receptor.

9. The system of claim **1**, wherein the compression arm assembly comprises a receptor housing, wherein the x-ray image receptor is disposed within the receptor housing and is configured to rotatably rock about the axis therein.

10. The system of claim **9**, wherein the movement of the x-ray tube assembly and the x-ray image receptor are at different angles about the axis for at least one of the plurality of imaging modes.

11. A system for multi-mode breast x-ray imaging comprising:

a housing;
 an arm assembly rotatably secured to the housing;
 a receptor housing attached to the arm assembly;
 a compression paddle movably attached to the arm assembly;
 a patient shield attached to the arm assembly;
 an x-ray image receptor rotatably supported by the housing and disposed within the receptor housing; and
 an x-ray tube assembly having an x-ray source disposed at least partially therein, wherein the x-ray tube assembly is rotatably supported by the housing, wherein the arm assembly and the x-ray tube assembly are independently rotatable in relation to the housing, and wherein when the x-ray tube assembly rotates independently from the arm assembly,
 the patient shield is spaced apart from the x-ray tube assembly such that the x-ray tube assembly rotates independently from at least a portion of the patient shield.

12. The system of claim **11**, wherein the patient shield is configured to provide a mechanical interlock against patient contact with the rotating x-ray source.

13. The system of claim **11**, wherein the x-ray tube assembly moves continuously for image acquisition when the x-ray tube assembly rotates relative to the arm assembly.

14. The system of claim **11** further comprising an anti-scatter grid disposed between the compression paddle and the x-ray image receptor.

15. The system of claim **14**, wherein the anti-scatter grid is retractable in relation to the x-ray image receptor.

16. The system of claim **11**, wherein the compression paddle is laterally moveable on the arm assembly.

17. The system of claim **11**, wherein the compression paddle is removable from the arm assembly.

11

12

18. The system of claim **11** further comprising a spacer disposed between the compression paddle and the x-ray image receptor.

* * * * *